AFWAL-TR-81-4081

CHARACTERIZATION OF REPAIR ADHESIVES FOR SHELTERS

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The primary objective of this investigation was to measure the lap-shear and stress-durability behavior of several shelter repair adhesive candidates as a function of time, temperature, and environmental exposure. Eight different two-part paste adhesives were tested at temperatures up to 200°F (93°C). Results for six of these adhesives are discussed and presented in the text. For the other two adhesives, added late in the program, the test data are presented in the Appendices without discussion or analysis in the text. Of the six

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adhesives discussed in the text, three withstood the combined elevated temperature, high humidity exposure conditions very well relative to the other three. One of the six performed quite poorly relative to the other five.

PREFACE

This report covers the work performed during the period from March 1979 to August 1981 under Air Force Contract Nos. F33615-78-C-5002 and F33615-80-C-5011, Project 7381. The work was administered under the direction of the Systems Support Division of the Air Force Materials Laboratory, Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Mr. John Rhodehamel (AFWAL/MLSE) was the Program Project Engineer.

The Principal Investigators on this program were James McKiernan and Ronald Kuhbander. The major portion of the laboratory work was conducted by Messrs. James McKiernan and Steven Caldwell.

This report was submitted by the author in August 1981. The contractor's report number is UDR-TR-81-55.

Other interim technical reports issued under this contract include AFWAL-TR-80-4135, AFWAL-TR-80-4183, AFWAL-TR-81-4011, AFWAL-TR-81-4129, and AFWAL-TR-80-4094.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Concluded)

SECTION 1
BACKGROUND AND INTRODUCTION

The Air Force, as well as the other services, has been utilizing lightweight, air transportable shelters for a wide variety of purposes for a number of years. Some of the many uses for these type shelters include the housing of personnel, hospital facilities, offices, and electronic instrument stations.

Modular building concepts incorporating such features as sandwich wall construction and adhesive bonding are routinely used for these structures to reduce production costs. Walls can consist of honeycomb or foam cores between aluminum skins. In addition to the skin-to-core bonding found in honeycomb-stiffened wall construction, adhesives are also used for metal-to-metal lap-type joints, and frequently serve both as a load bearing structural member as well as a joint sealant against environmental infiltration.

Shelters of this sort are used in many locations throughout the world, and consequently are subjected to a wide variety of environmental exposure conditions. These range from subzero arctic temperatures to hot, dry desert climates as well as hot, humid tropical conditions. Besides exposure to these various climatic extremes, the shelters are periodically subjected to abnormal stresses of transport from one location to another, exacerbating the demands made upon the structural members and bonded joints.

The shelter design requirements which most heavily influence the type of adhesives selected for use in structural bonding are

(a) minimum and maximum exposure temperatures of -70°F (-57°C) to 160°F (71°C) [skin temperatures ranging from -70°F (-57°C) to 200°F (93°C)] with concomitant interior-to-exterior thermal gradients coupled with varying humidity conditions up to saturation,

(b) water and corrosion resistance,

(c) overall stress loads up to 1200 psi (8.27 MPa), and

(d) long-term durability of up to fifteen (15) years of in-the-field use.

Experience has demonstrated that the hot-humid environment is the most demanding and that the adhesively bonded joints in these structures are the sites most susceptible to failure as a result of exposure to the stresses and climatic conditions described above.[1]

When the bonded joints on these structures fail, repairs usually are made with different adhesives than were used in the original construction of the shelter. The adhesives used to repair the failed joints are usually a spreadable paste type material because adhesive must be applied by hand to a sometimes vertical and perhaps less than freely accessible surface.

The primary objective of this investigation was to measure the lap shear and stress-durability behavior of several shelter repair adhesive candidates as a function of temperature and environmental exposure. No judgement of either the acceptability or unacceptability of any of the adhesives characterized in this program is made. Rather, the adhesives are comparatively evaluated, discussed, and ranked relative to each other.

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[1] From JOCOTAS (Joint Committee on Tactical Shelters, U.S. Army Natick Research Labs, Natick, Massachusetts).

SECTION 2
APPROACH

The adhesive characteristic of basic interest in this evaluation effort was the ability to resist the combination of elevated temperature and high humidity degradation. Although a quantitative accept/reject criteria for this characteristic has not yet been defined, the various adhesives evaluated can at least be compared to each other and given a form of overall ranking.

Two types of tests were used for the adhesive evaluations conducted during this program: lap shear and stress-durability. Lap shear tests were conducted to measure the effect of both elevated temperature and humidity aging upon adhesive properties. The environmental exposure conditions were selected to correspond to those measured on shelters in the field [up to 200°F (93°C) and 95-100 percent relative humidity]. Stress-durability tests were conducted to measure the simultaneous effects of stress, elevated temperature, and high humidity upon adhesive bond line. The environmental exposure conditions for these were the same as for the lap shear tests.

2.1 MATERIALS AND PROCESSES

There were two material variables of interest to this investigation, adherend alloy and adhesive. All of the bonded joints were prepared using the same adherend surface preparation and the same surface primer.

The two adherend materials were bare 5052H34 and 6061T6 aluminum alloys. These represent the two principle aluminum alloys used in shelter construction today.

The surface preparation procedure used for the adhesive bonding work in this program was phosphoric acid anodization, in general accordance with ARP-1524. Details of this surface treatment technique are presented in Appendix A.

A corrosion inhibiting primer, BR127 by American Cyanamid, was used for all bonds made during the program. Appendix B describes the primer application procedures.

Eight vendor-supplied adhesives were evaluated. These, to the best of our knowledge, were all modified epoxies. Five of the adhesives were in the program from the start, one was added after the program was started and was evaluated on only one adherend alloy, and two were added very late in the program. The data for these last two is not presented or discussed in the text of this report but it is given in Appendix H without discussion. These eight adhesives are listed in Table 1.

TABLE 1

ADHESIVES TESTED

Adhesive Designation	Source	Form	Comments
EA9320	Hysol	Two-part paste	
EA9324	Hysol	Two-part paste	
EC3501	3M	Two-part paste	
EA934	Hysol	Two-part paste	
Epibond 1524	Furane	Two-part paste	
EA934NA	Hysol	Two-part paste	Added late. Same as EA934 except contains no asbestos.
EC2216	3M	Two-part paste	Added very late. In current use for shelter repair.
EC2054	3M	Two-part paste	Added very late. In current use for shelter repair.

These eight adhesives were selected because they were either in current use in shelter repair or because they had been identified as likely candidates for use in shelter repair. Appendix E presents data provided for each of these adhesives by their manufacturer.

2.2 SPECIMEN FABRICATION PROCEDURES

The fabrication of the specimens used for data generation in this program consisted of a sequence of five distinct processes:

(1) Adherend surface preparation,
(2) Priming of freshly prepared adherend surface,
(3) Bonded joint panel layup,
(4) Curing of adhesive joint panel, and
(5) Machining of individual specimens from cured panel.

Each of these five processes is described in detail in Appendices A through D, respectively. These include step-by-step descriptions of each procedure, as well as the quality control criteria used to accept/reject a part or finished panel at each step in the fabrication sequence.

2.3 TEST METHODS AND EXPERIMENTAL DESIGN

All testing conducted during this investigation was performed in accordance with standardized procedures.

2.3.1 Lap Shear Testing

Lap shear tests were conducted in accordance with ASTM method D1002 on specimens from the standard (machined after bonding) type of test panel. The acceptable range of primer thickness, as recommended by the primer manufacturer, was 0.0002-0.0004 inch (0.005-0.010 mm), while the acceptable range of glueline thickness, as established by a consensus of shelter manufacturers at the start of the program, was 0.004-0.007 inch (0.10-0.18 mm). The techniques used to measure these thicknesses are described in Appendices B and C, respectively. Any specimens with applied primer or cured glueline thickness outside of these limits were rejected.

Lap shear tests were conducted at -65°F (-54°C), 72°F (22°C), 140°F (60°C), and 200°F (93°C) on dry unaged

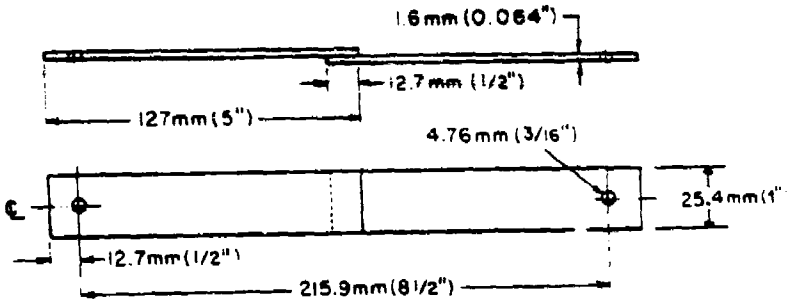
specimens and at 140°F (60°C) and 200°F (93°C) on specimens which had been environmentally aged for 14 days in 95-100 percent R.H. and 140°F (60°C) or 200°F (93°C), respectively, prior to testing.

2.3.2 Stress-Durability Testing

Stress-durability tests were conducted in accordance with ASTM method D2919 (see Figure 1). The same accept/reject criteria regarding primer and glueline thickness were followed with these specimens as with the lap shear specimens mentioned in Paragraph 2.3.1.

Stress-durability tests consisted of mounting the specimen in the fixture illustrated in Figure 1, imposing a predetermined shear stress upon the specimen, and placing the specimen-fixture assembly in an elevated temperature, high humidity aging environment until the specimen failed or the exposure period reached a preselected limit (672 hours in this program). In the event that the exposure period reached the 672 hour limit without specimen failure, the fixture was removed from the environmental cabinet, and the specimen unloaded and removed from the fixture and tested for residual strength. This test was aimed at providing additional data on the effect of environment upon adhesives. While not necessarily providing real-life design type data, it did provide a comparative ranking of adhesive resistance to environmental degradation.

Stress-durability tests were conducted in a 95-100 percent R.H. environment at both 140°F (60°C) and 200°F (93°C). Times to failure were recorded and any specimens which had not failed within 672 hours were removed and tested for residual strength at the same temperature they saw during the 672 hour exposure.



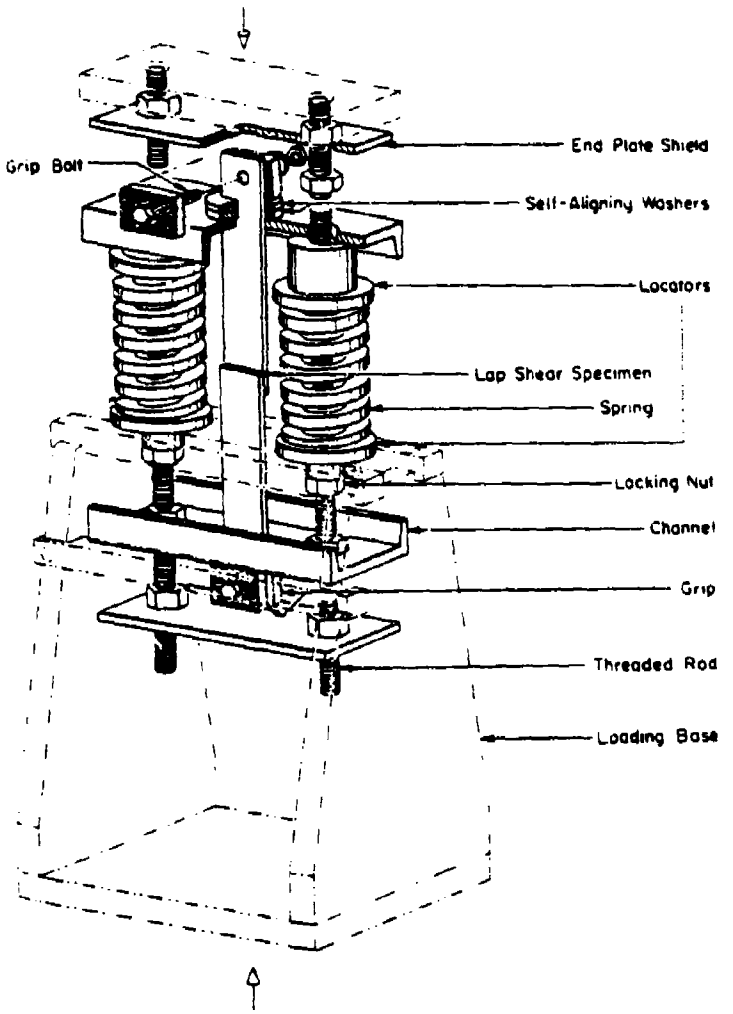


Figure 1. Lap Shear Specimen and Stress-Durability Fixture (from ASTM D2919).

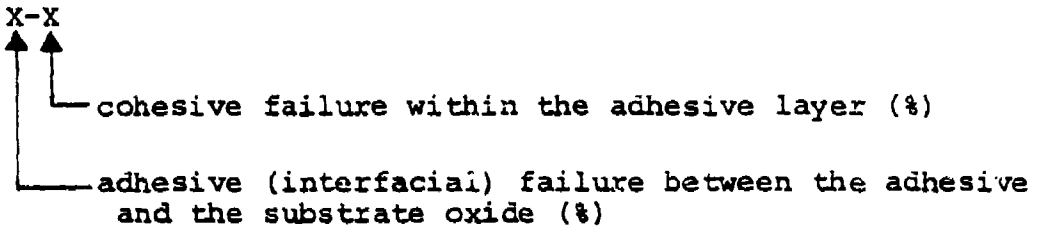
SECTION 3
DISCUSSION OF RESULTS

The interpretation and assessment of the results obtained in this investigation are based upon the measured strengths and times-to-failure, as well as the observed failure modes in the bond areas.

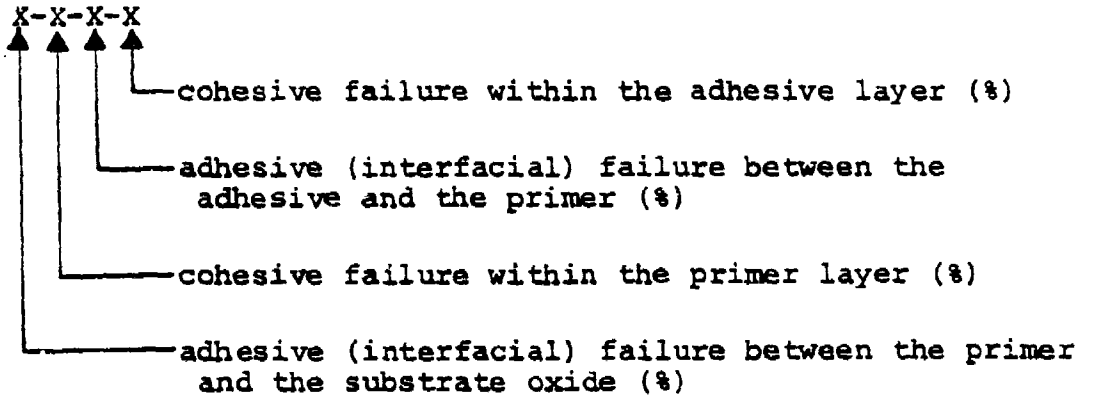
Traditionally, bonded joint failures have been reported as adhesive, cohesive, or some combination of the two. In this context, adhesive failure referred to a failure locus along the interface between the substrate and the adhesive layer, while cohesive failure referred to a failure locus completely within the adhesive layer. It was felt that with the inclusion of a primer layer in the bond, along with but distinct from the adhesive layer, the traditional means of reporting failure mode was inadequate. Accordingly, a different format for reporting failure mode was utilized during this investigation. This format is illustrated and explained in Figure 2.

The interpretation of bonded joint failure modes is very subjective. It is difficult, with the naked eye, to ascertain the exact failure mode unless it is totally cohesive (within the adhesive layer). Interfacial failure modes may appear obvious but one cannot be sure, short of resorting to expensive surface instrumental analysis, that a very thin layer of primer or adhesive has not remained adhered to an otherwise clean appearing surface. Since the primer layer is so thin, the only evidence of its presence, to the eye, is generally color. In this investigation the only discriminations made regarding failure mode were those detectable by eye. Thus, it is to be recognized that regardless of the different presentation format, the failure modes reported in this document are still subjective.

For Bonds Made With No Primer



For Bonds Made With a Primer on the Substrate Surface



Example: 5-0-30-65 indicates that, according to the observer's estimate, the failed joint exhibits the following failure mode.

The primer pulled cleanly off the metallic oxide on 5% of the bond area.

At no point along the bondline did the failure locus run cohesively within the primer layer.

The adhesive debonded cleanly from the primer on 30% of the bond area.

The failure locus ran cohesively within the adhesive layer on 65% of the bond area.

Figure 2. Explanation of Failure Mode Notation.

3.1 LAP SHEAR TEST RESULTS

The data obtained from the testing of the lap shear specimens are summarized in Tables 2 through 4. The data in Tables 2 through 4 are also presented graphically in Figures 3 and 4. A comprehensive listing of all of the individual specimen-by-specimen lap shear test data is presented in Appendix F.

In general, three adhesives (Epibond 1524, EA9324, and EA934) retained a substantial level of lap shear strength after combined elevated temperature and high humidity aging. One adhesive (EA9320) retained relatively high strength levels up to 140°F (60°C) but lost significantly more of its strength at 200°F (93°C) than the previous three. The fifth adhesive (EA934NA) was evaluated on only one alloy. It also retained relatively high strength levels up through 140°F (60°C), like the EA9320, but fell off at 200°F (93°C). The sixth adhesive (EC3501) was by far the least satisfactory of the five evaluated here. It had very little strength at -65°F (-54°C), 200°F (93°C) or after hot, humid aging at either 140°F (60°C) or 200°F (93°C).

By comparison of the property levels and failure modes obtained for various combinations of test conditions, one can separate the effects of temperature and humidity aging on the behavior of the various adhesives. The following paragraphs discuss the observations arising out of such a comparison.

Epibond 1524: The effect of temperature on dry unaged bonds with this adhesive is noted primarily at -65°F (-54°C) where the strength is 40 to 70 percent of its room temperature level. At 200°F (93°C) the strength levels are only 15 to 20 percent lower than the room temperature values. This adhesive exhibits a predominance of adhesive-to-primer interfacial failures at most all of the test temperatures.

The two-week humid aging on this adhesive caused no degradation on the 5052H34 substrate adherend. On the 6061T6 alloy, however, the strength after aging was about 20 percent less than in the unaged condition. This strength decrease

TABLE 2

LAP SHEAR TEST RESULTS FOR SHELTER REPAIR ADHESIVES AT -65°F (-54°C) AND 72°F (22°C)

Adherend Material	Adhesive	Test Temperature[1]					
		-65°F (-54°C)			72°F (22°C)		
		Lap Shear Str.[2] (psi)	(MPa)	Failure Mode	Lap Shear Str.[3] (psi)	(MPa)	Failure Mode
5052H34	EA9320	4120	28.4	10-0-80-10	4320	29.7	0-0-80-20
	EA9324	2170	15.0	0-0-100-0	3540	24.4	0-0-80-20
	EC3501	270	1.9	0-0-100-0	2230	15.4	0-0-90-10
	EA934	2330	16.1	0-0-0-100	3370	23.2	0-0-100-0
	Epibond 1524	2680	18.5	0-0-0-100	3990	27.5	0-0-100-0
6061T6	EA9320	4810	33.1	10-10-80-0	4930	34.0	10-0-70-20
	EA9324	2530	17.4	0-0-100-0	3710	25.6	0-0-70-30
	EC3501	220	1.5	0-0-100-0	1990	13.7	0-0-100-0
	EA934	2590	17.9	0-0-100-0	3370	23.2	0-0-90-10
	EA934NA	3130	21.6	0--5-95-0	3840	26.5	0-5-70-25
	Epibond 1524	1500	10.3	0-0-100-0	3620	24.9	0-0-70-30

[1]Specimens held at temperature 10 minutes before testing.
[2]Represents an average of three-to-five specimens.
[3]Represents an average of five specimens.

TABLE 3

LAP SHEAR TEST RESULTS FOR SHELTER REPAIR ADHESIVES AT 140°F (60°C) AND 200°F (93°C)

Adherend Material	Adhesive	Test Temperature[1] 140°F (60°C) Lap Shear Str.[2] (psi)	(MPa)	Failure Mode	200°F (93°C) Lap Shear Str.[2] (psi)	(MPa)	Failure Mode
5052H34	EA9320	3420	23.6	0-0-0-100	1670	11.5	0-0-30-70
	EA9324	3270	22.5	0-0-10-90	2560	17.6	0-0-0-100
	EC3501	1310	9.1	0-0-60-40	580	4.0	0-0-10-90
	EA934	3280	22.6	5-0-30-65	2530	17.4	0-0-40-60
	Epibond 1524	3350	23.1	0-0-80-20	3160	21.8	0-0-50-50
6061T6	EA9320	4180	28.8	0-0-0-100	2300	15.9	0-0-10-90
	EA9324	3410	23.5	0-0-0-100	2240	15.4	0-0-0-100
	EC3501	1170	8.1	0-0-70-30	470	3.2	0-0-40-60
	EA934	3170	21.8	0-0-30-70	2480	17.1	0-0-25-75
	EA934NA	2980	20.5	0-0-20-80	1695	11.7	0-0-25-75
	Epibond 1524	3470	23.9	0-0-90-10	3130	21.6	5-5-65-25

[1]Specimens held at temperature 10 minutes prior to test.
[2]Represents an average of eight-to-ten specimens (except for EA934NA, in which case only five specimens were tested).

TABLE 4

LAP SHEAR TEST RESULTS FOR SHELTER REPAIR ADHESIVES AT 140°F (60°C) AND 200°F (93°C) AFTER ENVIRONMENTAL AGING

Adherend Material	Adhesive	Test Condition: 140°F (60°C) After Aging[1] Lap Shear Str.[3] (psi)	(MPa)	Failure Mode	Test Condition: 200°F (93°C) After Aging[2] Lap Shear Str.[3] (psi)	(MPa)	Failure Mode
5052H34	EA9320	4320	29.7	0-0-80-20	1130	7.8	0-0-60-40
	EA9324	3540	24.4	0-0-80-20	2360	16.3	0-0-0-100
	EC3501	560	3.9	0-0-10-90	400	2.8	0-0-10-90
	EA934	3370	23.2	0-0-100-0	2410	16.6	0-0-40-60
	Epibond 1524	3990	27.5	0-0-100-0	3140	21.6	0-20-40-40
6061T6	EA9320	3950	27.2	0-0-10-90	1430	9.8	0-0-70-30
	EA9324	3820	26.3	0-0-20-80	2935	20.2	0-0-5-95
	EC3501	670	4.6	0-0-5-95	450	3.1	0-0-20-80
	EA934	3510	24.2	0-10-50-40	2370	16.3	0-0-30-70
	EA934NA	2320	16.0	0-0-25-75	1545	10.7	0-0-65-35
	Epibond 1524	2790	19.2	0-40-55-5	2590	17.9	0-20-50-30

[1]Aging consisted of fourteen days at 140°F (60°C) and 95-100% R. H.
[2]Aging consisted of fourteen days at 200°F (93°C) and 95-100% R. H.
[3]Represents an average of five specimens.

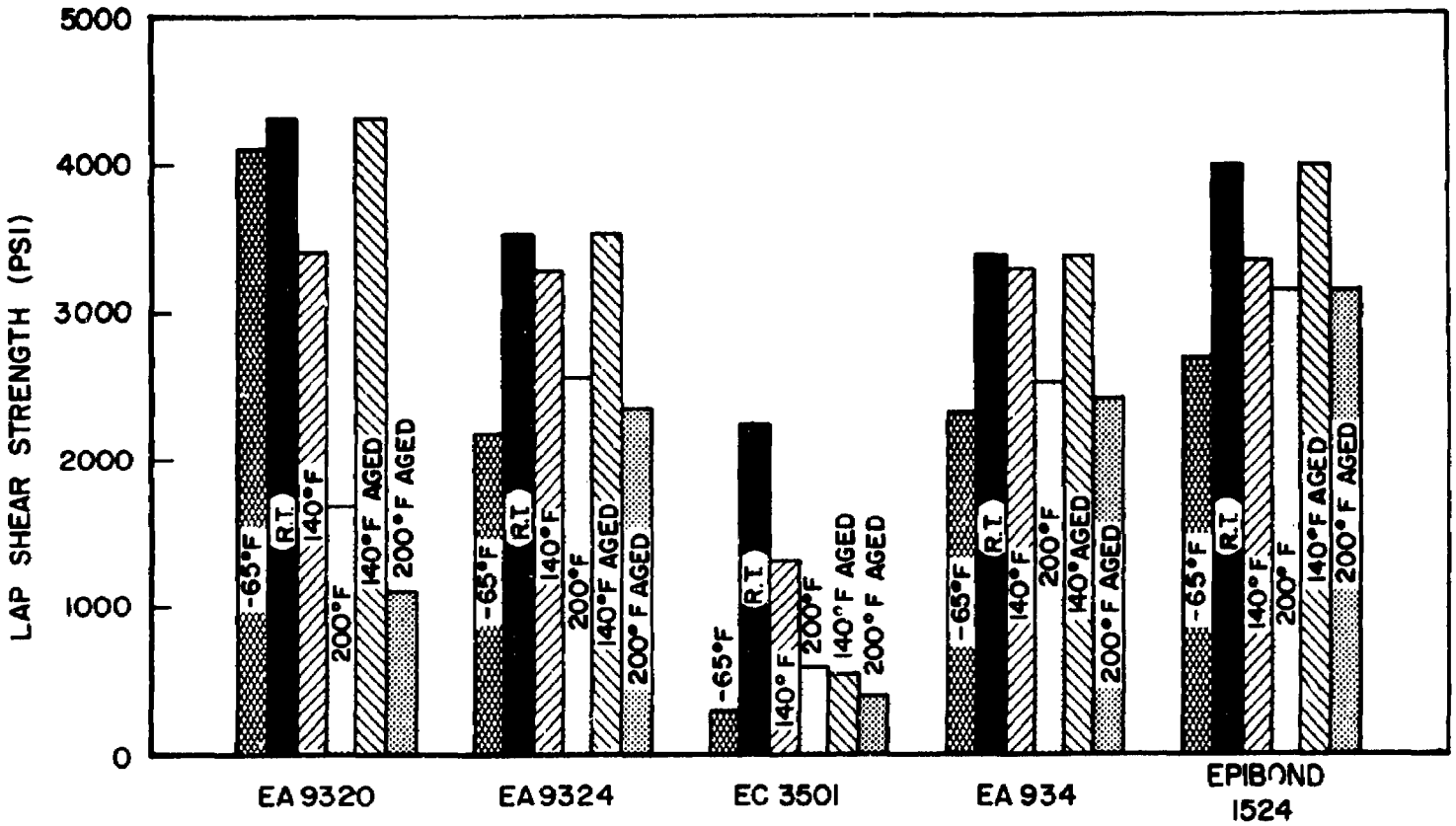


Figure 3. Effect of Test Temperature and Environmental Aging on Lap Shear Strength of Shelter Repair Adhesives on 5052H34 Bare Aluminum Adherends.

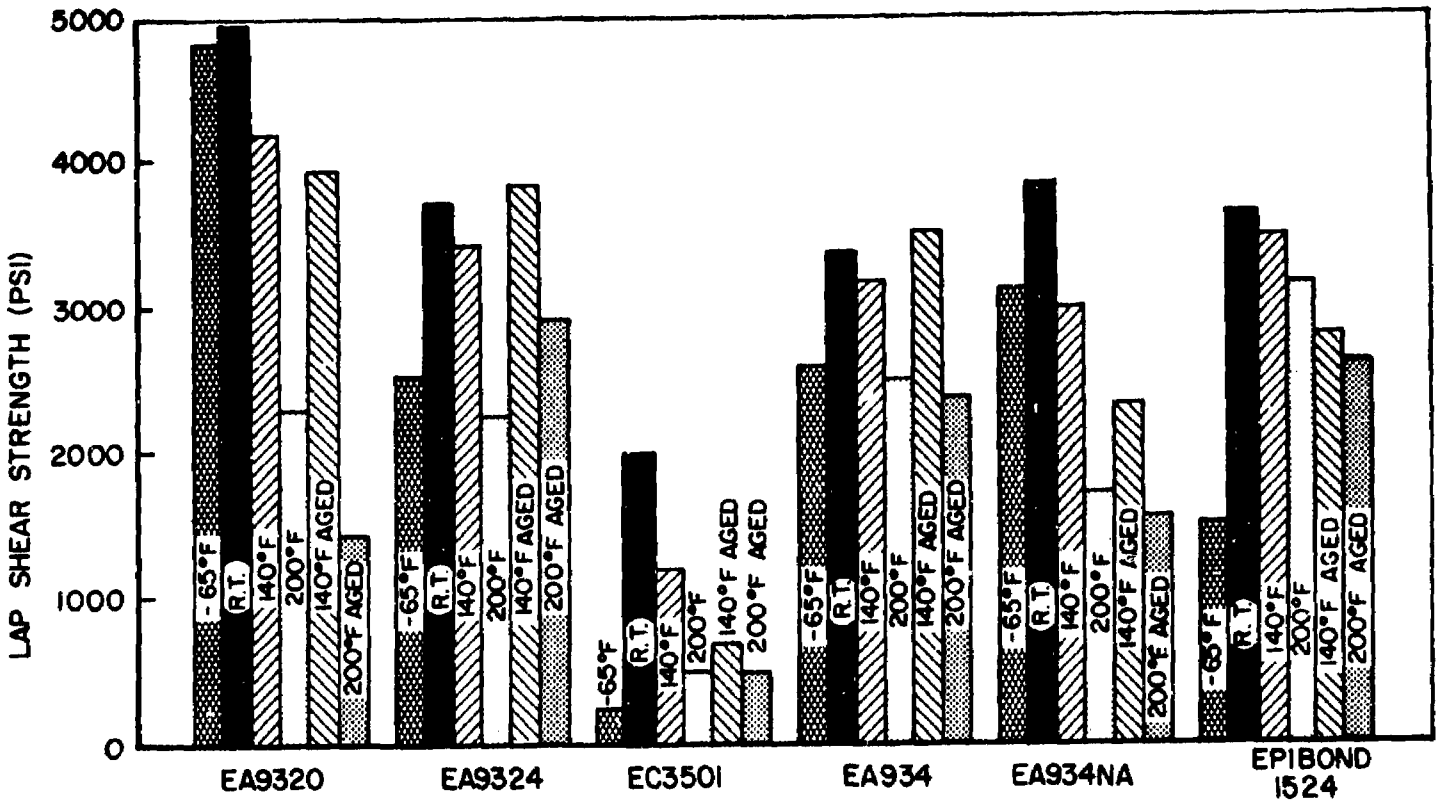


Figure 4. Effect of Test Temperature and Environmental Aging on Lap Shear Strength of Shelter Repair Adhesives on 6061T6 Bare Aluminum Adherends.

on the 6061T6 alloy after humid aging is accompanied by an increase in the percentage of failure which occurs within the primer layer.

EA9324: This adhesive is only about two-thirds as strong at -65°F (-54°C) as it is at room temperature. At 140°F (60°C) and 200°F (93°C) it loses about 10 percent and 35 percent, respectively, of its room temperature strength.

The two week humid aging on this adhesive did not seem to cause any degradation at all. In fact the residual lap shear strength after the aging period was higher than the strength of the unaged adhesive at the same temperature in three of the four cases, and only slightly reduced (~8 percent) in the fourth.

At the two lower test temperatures, this adhesive exhibited a predominantly adhesive-to-primer interfacial failure mode, while at the two higher test temperatures, both aged and unaged, the failure mode was predominantly cohesive within the adhesive layer.

EA934: This adhesive is 70 to 75 percent as strong at -65°F (-54°C) as it is at room temperature. It loses very little strength up to 140°F (60°C) and at 200°F (93°C) is still about 75 percent as strong as it is at room temperature.

The two week humid aging have practically no effect on the strength of lap shear joints made with this adhesive in comparison with unaged joints tested at the same temperature.

This adhesive exhibits a combination of adhesive-to-primer interfacial and cohesive failures within the adhesive layer.

EA9320: This adhesive exhibited excellent low temperature lap shear strength (nearly equivalent to its room temperature values) and also exhibited the highest strengths at 140°F (60°C) of any of the six adhesives tested. At 200°F (93°C), however, its strength, while still respectable, was only about 40 to 45 percent of its room temperature value.

The two-week humid aging produced no loss of properties at 140°F (60°C) but at 200°F (93°C) the strength of the aged adhesive joints was only about 60 to 70 percent of the unaged strength at the same temperature, and the unaged strength at this temperature was already substantially reduced from the lower temperature levels.

At the two lower test temperatures this adhesive exhibits a predominantly interfacial, adhesive-to-primer, failure mode. At the two

higher temperatures, in the unaged condition, the failure mode shifts to predominantly cohesive within the adhesive layer. The joints which were humidity aged at the two higher temperatures exhibited primarily an adhesive-to-primer interfacial failure although varying percentages of adhesive layer failures (cohesive) were also present in the aged joints.

EA934NA: This adhesive, on 6061T6 aluminum, was second only to the EA9320 adhesive at the two lower test temperatures in lap-shear strength. At the two higher test temperatures, however, and particularly at 200°F (93°C), this adhesive falls below all of the adhesives except EC3501, even though its strength is still respectable at these temperatures.

The two week humid agings resulted in a 20 percent decrease in 140°F (60°C) lap shear strength and a 10 percent decrease in 200°F (93°C) lap shear strength.

At the two lower test temperatures this adhesive exhibits a predominantly interfacial, adhesive-to-primer failure mode. At the two higher temperatures, the failure shifts into the adhesive layer itself (cohesive), although at 200°F (93°C) the aged specimens exhibited more interfacial adhesive-to-primer failure than adhesive layer (cohesive) failure.

EC3501: This adhesive is very temperature sensitive. It retains only about 12 percent of its room temperature strength at -65°F (-54°C). At 140°F (60°C) and 200°F (93°C), respectively, it loses 40 percent and 75 percent of its room temperature strength.

Humidity aging of this adhesive caused a 50 percent strength loss at 140°F (60°C) compared to unaged strength at the same temperature. At 200°F (93°C) the two week humid aging caused a 20 percent decrease in strength compared to the unaged strength at this temperature.

At the two lower test temperatures this adhesive failed almost exclusively along the adhesive-to-primer interface. At 140°F (60°C) this same interfacial failure mode still predominates but considerably more of the failure is occurring within the adhesive layer than at the lower temperatures. At 200°F (93°C) the failure locus has shifted to predominantly within the adhesive layer with a little adhesive-to-primer interfacial separation still present. After humid aging at both elevated temperatures, this adhesive fails predominantly within the adhesive layer (cohesively).

To summarize the lap shear results, an arbitrary rating system has been adopted. Since the primary interest in this investigation was to assess the combined effects of both temperature and humidity upon the adhesive's performance, only the test results obtained after the two week aging periods at 140°F (60°C) and 200°F (93°C) have been considered in establishing these ratings. Each adhesive was scored by awarding from 0 to 5 points to the adhesive based upon the lap shear strength it retained after the aging period (Table 4). Table 5 presents the scoring criteria and Table 6 presents the scoring results. These scores, in addition to those to be generated subsequently for the stress-durability tests, will be used to comparatively rate the adhesives.

3.2 STRESS-DURABILITY TEST RESULTS

The data obtained from the lap-shear stress-durability tests are summarized in Tables 7 through 10 and illustrated in Figures 5 through 8. A comprehensive listing of all of the individual specimen-by-specimen stress-durability test data is presented in Appendix G.

The stress levels to which the specimens were subjected during the elevated temperature, high humidity stress-durability exposures were based upon the lap shear strengths of unaged, as-fabricated specimens tested at the same temperature. These baseline values are presented in Table 3, Paragraph 3.1.

The relative stress-durability of the adhesives tested in this program is most readily ascertained by inspection of Figures 5 through 8, with supplementary reference to the data in Tables 7 through 10 for failure mode and residual property information.

It can be observed from Figures 5 and 6 that for the 140°F (60°C) exposure temperature, and on both adherend materials, the Epibond 1524 adhesive exhibits the best stress-durability

TABLE 5

SCORING CRITERIA FOR AGED LAP SHEAR STRENGTHS

Strength Level Retained After Aging Period		Scoring Value
psi	(MPa)	
over 3000	over 20.67	5
2500-3000	17.62-20.67	4
2000-2500	13.78-17.23	3
1500-2000	10.34-13.78	2
1000-1500	6.89-10.34	1
under 1000	under 6.89	0

TABLE 6

ADHESIVE SCORES FOR AGED LAP SHEAR TESTS

Adhesive	Adherend Alloy	140°F(60°C) Wet Aged	200°F(93°C) Wet Aged	Averages 140°F(60°C) Wet Aged	Averages 200°F(93°C) Wet Aged
EA9320	5052H34	5	1	5.0	1.0
	6061T6	5	1		
EA9324	5052H34	5	3	5.0	3.5
	6061T6	5	4		
EC3501	5052H34	3	0	1.5	0
	6061T6	0	0		
EA934	5052H34	5	3	5.0	3.0
	6061T6	5	3		
Epibond 1524	5052H34	5	5	4.5	4.5
	6061T6	4	4		
EA934NA	5052H34	---	---	---	---
	6061T6	3	2	3.0	2.0

TABLE 7

STRESS-DURABILITY TEST RESULTS FOR 140°F(60°C), 100% R.H. EXPOSURE CONDITIONS ON 5052H34 ALUMINUM ADHERENDS

Adhesive	Exposure Stress (psi)	(MPa)	(%)	Hrs. to Failure	No. of Specimens	Failure Mode	Residual Strength (psi)	(MPa)	(%)	No. of Specimens	Failure Mode
EA 9320	1710	11.8	50	70±72	8	0-0-30-70	---	---	---	0	---
	1540	10.6	45	137±167	9	0-0-30-70	---	---	---	0	---
	1370	9.4	40	>332±245	10	0-0-40-60	3435	23.7	---	2	5-0-35-60
EA 9324	1960	13.5	60	188±193	3	0-0-0-100	---	---	---	0	---
	1640	11.3	50	>376±317	8	0-0-15-85	3605	24.9	---	2	0-0-30-70
	1470	10.1	45	>474±284	8	0-0-25-75	3440±260	23.7±1.8	---	4	0-0-30-70
	1310	9.0	40	>672	6	---	3780±230	26.1±1.6	---	6	0-0-40-60
EA 934	1800	12.5	55	261±121	3	0-0-20-80	---	---	---	0	---
	1640	11.3	50	>549±145	7	0-0-35-65	3150	21.7	---	2	0-0-60-40
	1480	10.2	45	>593±174	7	0-0-50-50	3050±310	20.7±2.1	---	5	0-0-50-50
	1310	9.0	40	>672	6	---	3240±290	22.3±2.0	---	6	0-0-60-40
EC 3501	390	2.7	30	3±4	6	0-0-70-30	---	---	---	0	---
	330	2.3	25	>224±308	7	0-0-40-60	810	5.6	---	2	0-0-10-90
	260	1.8	20	>299±302	9	0-0-30-70	740±90	5.1±0.6	---	3	0-0-10-90
Epibond 1524	2350	16.2	70	250	1	0-0-80-20	---	---	---	0	---
	2010	13.9	60	>672	1	---	3690	25.4	---	1	0-30-50-10
	1840	12.7	55	>672	1	---	3540	24.4	---	1	0-100-0-0
	1680	11.6	50	>672	5	---	3430	23.6	---	5	0-20-60-20

NOTES:

1. Stress durability tests conducted according to ASTM D2919.
2. All adherends were given a phosphoric acid anodized surface treatment (see Appendix I).
3. The values in the two columns labeled (%) represent the percent of the baseline strength corresponding to the listed exposure stress or residual strength. The baseline strength is the strength of the unaged, as fabricated adhesive at 140°F (60°C) listed in Table 3.
4. Exposures were terminated after 672 hours (28 days) if specimens had not yet failed. These surviving specimens were tested for residual strength at 140°F (60°C).
5. Those average values listed with a greater than (>) sign in front of the hours to failure include one or more specimens which ran out to 672 hours without failure. The average time-to-failure would therefore have been greater than indicated had these tests been continued beyond 672 hours.
6. The ± values listed in the table represent standard deviations and are included only where at least three values are included in the data set.

TABLE 8

STRESS-DURABILITY TEST RESULTS FOR 140°F(60°C), 100% R.H. EXPOSURE CONDITIONS ON 6061T6 ALUMINUM ADHERENDS

Adhesive	Exposure Stress (psi)	(MPa)	(%)	Hrs. to Failure	No. of Specimens	Failure Mode	Residual Stress (psi)	(MPa)	(%)	No. of Specimens	Failure Mode
EA 9320	1670	11.5	40	69±40	3	0-0-40-60	---	---	---	0	---
	1460	10.1	35	112±56	4	0-0-50-50	---	---	---	0	---
	1250	8.6	30	224±97	7	0-0-35-65	---	---	---	0	---
	1050	7.2	25	372±155	7	0-0-45-55	---	---	---	0	---
EA 9324	1880	12.9	55	>195±236	7	0-0-5-95	4000	27.6	---	1	0-0-0-100
	1710	11.7	50	>464±217	7	0-0-10-90	3860±1205	26.6±8.3	---	3	0-0-15-85
	1530	10.6	45	>506±170	6	0-0-10-90	4060	28.0	---	1	0-0-20-80
	1360	9.4	40	>672	4	---	4520±320	31.1±2.2	---	4	0-0-25-75
EA 934	2060	14.2	65	284	1	0-0-30-70	---	---	---	0	---
	1900	13.1	60	>403±268	7	0-0-25-75	3120	21.5	---	1	0-0-40-60
	1740	12.0	55	>438±199	6	0-0-35-65	3970	27.4	---	1	0-0-80-20
	1590	10.9	50	>514±236	5	0-0-30-70	3540	24.4	---	2	0-5-35-60
	1430	9.8	45	>672	1	---	3370	23.2	---	1	0-0-30-70
EC 3501	410	2.8	35	13±15	10	0-0-45-55	---	---	---	0	---
	350	2.4	30	>591±214	7	0-0-30-70	735±98	5.1±0.7	---	6	0-0-10-90
Epibond 1524	2430	16.7	70	395	1	0-0-20-80	---	---	---	0	---
	2260	15.6	65	>672	2	---	4475	30.8	---	2	0-15-70-15
	2080	14.4	60	>550±156	3	0-10-55-35	4050	27.9	---	1	0-100-0-0
	1910	13.2	55	>672	3	---	3900±220	26.9±1.5	---	3	0-30-55-15
EA 934NA	1340	9.2	45	50±51	6	0-0-10-90	---	---	---	0	---
	1190	8.2	40	159±97	5	0-0-45-55	---	---	---	0	---
	1040	7.2	35	369±240	5	0-0-45-55	---	---	---	0	---

NOTES:

1. Stress durability tests conducted according to ASTM D2919.
2. All adherends were given a phosphoric acid anodized surface treatment (see Appendix I).
3. The values in the two columns labeled (%) represent the percent of the baseline strength corresponding to the listed exposure stress or residual strength. The baseline strength is the strength of the unaged, as fabricated adhesive at 140°F (60°C) listed in Table 3.
4. Exposures were terminated after 672 hours (28 days) if specimens had not yet failed. These surviving specimens were tested for residual strength at 140°F (60°C).
5. Those average values listed with a greater than (>) sign in front of the hours to failure include one or more specimens which ran out to 672 hours without failure. The average time-to-failure would therefore have been greater than indicated had these tests been continued beyond 672 hours.
6. The ± values listed in the table represent standard deviations and are included only where at least three values are included in the data set.

TABLE 9

STRESS-DURABILITY TEST RESULTS FOR 200°F(93°C), 100% R.H. EXPOSURE CONDITIONS ON 5052H34 ALUMINUM ADHERENDS

Adhesive	Exposure Stress (psi)	(MPa)	(%)	Hrs. to Failure	No. of Specimens	Failure Mode	Residual Strength (psi)	(MPa)	(%)	No. of Specimens	Failure Mode
EA9320	420	2.9	25	8±6	6	0-0-60-40	---	---	---	0	---
	330	2.3	20	93±95	9	0-0-70-30	---	---	---	0	---
	250	1.7	15	>499±264	8	0-0-65-35	850±130	5.9±0.9	---	5	0-0-70-30
EA 9324	770	5.3	30	69±105	8	0-0-20-80	---	---	---	0	---
	640	4.4	25	133±77	3	0-0-20-80	---	---	---	0	---
	510	3.5	20	349±112	7	0-0-30-70	---	---	---	0	---
	380	2.6	15	>544±183	5	0-0-30-70	1870±260	12.9±1.8	---	3	0-0-5-95
EA 934	890	6.1	35	>318±245	6	0-0-20-80	1880	13.0	---	2	5-0-35-60
	760	5.2	30	>476±295	5	0-0-20-80	2120	14.6	---	2	0-0-40-60
	630	4.3	25	>454±212	6	10-0-25-65	1880	13.0	---	2	0-0-20-80
	510	3.5	20	>672	4	---	1870±330	12.9±2.3	---	4	0-0-30-70
EC 3501	200	1.4	35	>461±296	5	0-0-30-70	520±80	3.6±0.6	---	3	0-0-15-85
	170	1.2	30	>499±297	11	0-0-25-75	510±50	3.5±0.3	---	8	0-0-15-85
	120	0.8	20	>672	3	---	540±90	3.7±0.6	---	3	0-0-10-90
Epibond 1524	1260	8.7	40	2	2	0-0-25-75	---	---	---	0	---
	950	6.5	30	196±171	9	0-0-55-45	---	---	---	0	---
	790	5.4	25	>366±153	9	10-0-45-45	1390	9.6	---	1	0-0-30-70
	630	4.3	20	442±68	6	0-0-50-50	---	---	---	0	---

NOTES:

1. Stress durability tests conducted according to ASTM D2919.
2. All adherends were given a phosphoric acid anodized surface treatment (see Appendix I).
3. The values in the two columns labeled (%) represent the percent of the baseline strength corresponding to the listed exposure stress or residual strength. The baseline strength is the strength of the unaged, as fabricated adhesive at 200°F (93°C) listed in Table 3.
4. Exposures were terminated after 672 hours (28 days) if specimens had not yet failed. These surviving specimens were tested for residual strength at 200°F (93°C).
5. Those average values listed with a greater than (>) sign in front of the hours to failure include one or more specimens which ran out to 672 hours without failure. The average time-to-failure would therefore have been greater than indicated had these tests been continued beyond 672 hours.
6. The ± values listed in the table represent standard deviations and are included only where at least three values are included in the data set.

TABLE 10

STRESS-DURABILITY TEST RESULTS FOR 200°F(93°C), 100% R.H. EXPOSURE CONDITIONS ON 6061T6 ALUMINUM ADHERENDS

Adhesive	Exposure Stress (psi)	(MPa)	(%)	Hrs. to Failure	No. of Specimens	Failure Mode	Residual Stress (psi)	(MPa)	(%)	No. of Specimens	Failure Mode
EA 9320	460	3.2	20	18±2	7	0-0-60-40	---	---	---	0	---
	350	2.4	15	43±18	10	0-0-65-35	---	---	---	0	---
	230	1.6	10	>672	8	---	720±90	5.0±0.6	---	8	0-0-65-35
EA 9324	670	4.6	30	79±52	9	0-0-15-85	---	---	---	0	---
	560	3.9	25	178±91	9	0-0-15-85	---	---	---	0	---
	450	3.1	20	>531±148	9	0-0-30-70	1890±490	13.0±3.4	---	4	0-0-0-100
EA 934	870	6.0	35	173±152	9	0-0-15-85	---	---	---	0	---
	740	5.1	30	>549±139	6	0-0-30-70	2140±640	14.7±4.4	---	3	0-0-35-65
	620	4.3	25	>672	3	---	1960±270	13.5±1.9	---	3	0-0-25-75
EEC 3501	260	1.8	55	>404	2	0-0-20-80	580	4.0	---	1	0-0-10-90
	240	1.7	50	>453±316	6	0-0-25-75	620±50	4.5±0.3	---	3	0-0-15-85
	210	1.5	45	>672	3	---	570±5	3.9±	---	3	0-0-10-90
Epibond 1524	940	6.5	30	238±61	5	0-0-60-40	---	---	---	0	---
	780	5.4	25	335±176	7	0-0-60-40	---	---	---	0	---
	630	4.3	20	419±71	6	0-0-50-50	---	---	---	0	---
	470	3.2	15	>672	2	---	2080	14.3	---	2	0-0-35-65
EA 934NA	760	5.3	45	4	2	0-0-35-65	---	---	---	0	---
	680	4.7	40	71±150	5	0-0-40-60	---	---	---	0	---
	590	4.1	35	>595±205	7	0-0-20-80	1390±200	9.6±1.4	---	6	0-0-30-70
	510	3.5	30	>672	3	---	1490±230	10.3±1.6	---	3	0-5-30-65

NOTES:

1. Stress durability tests conducted according to ASTM D2919.
2. All adherends were given a phosphoric acid anodized surface treatment (see Appendix I).
3. The values in the two columns labeled (%) represent the percent of the baseline strength corresponding to the listed exposure stress or residual strength. The baseline strength is the strength of the unaged, as fabricated adhesive at 200°F (93°C) listed in Table 3.
4. Exposures were terminated after 672 hours (28 days) if specimens had not yet failed. These surviving specimens were tested for residual strength at 200°F (93°C).
5. Those average values listed with a greater than (>) sign in front of the hours to failure include one or more specimens which ran out to 672 hours without failure. The average time-to-failure would therefore have been greater than indicated had these tests continued beyond 672 hours.
6. The ± values listed in the table represent standard deviations and are included only where at least three values are included in the data set.

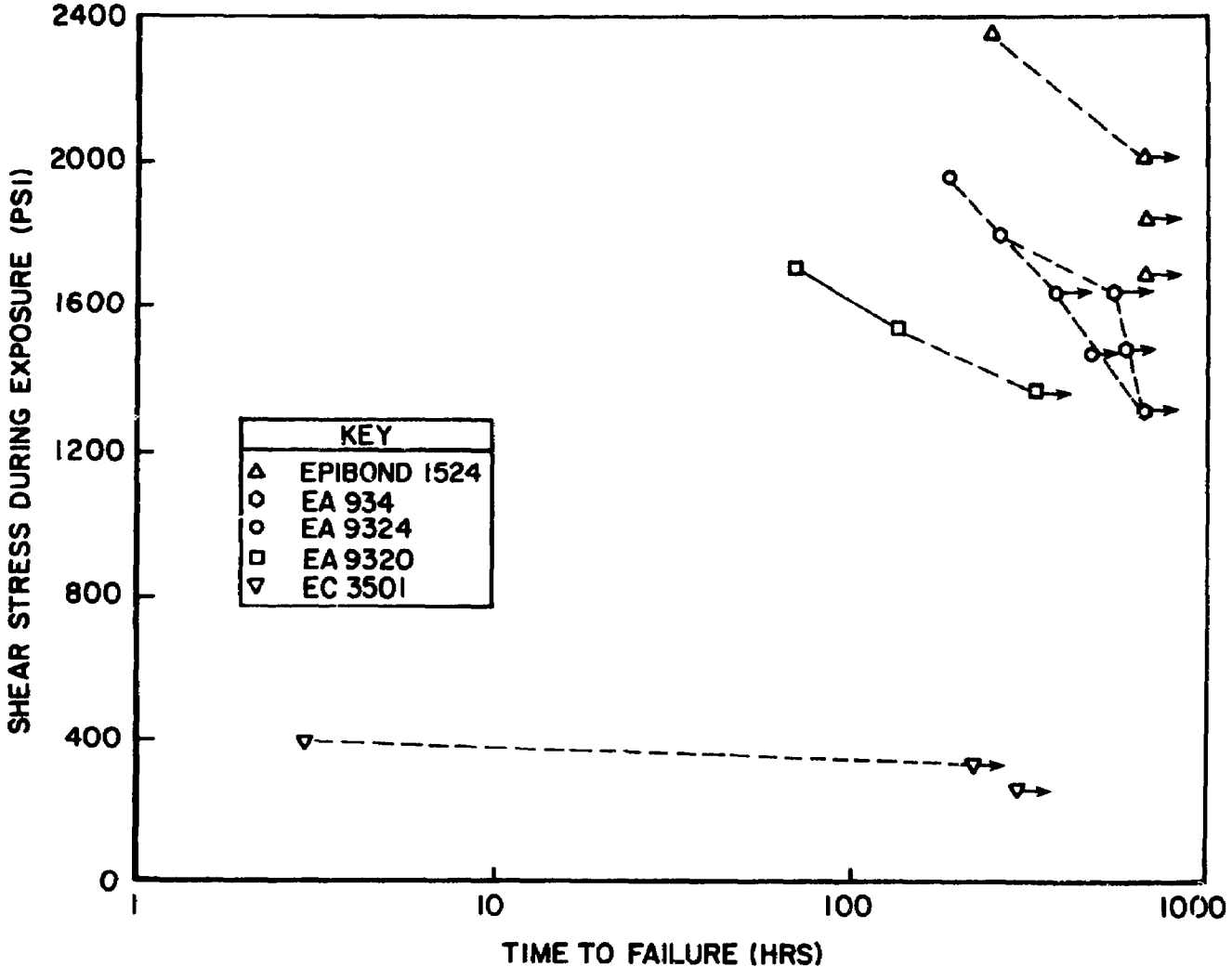


Figure 5. Stress-Durability Behavior on 5052H34 Bare Aluminum Adherends in a 140°F (60°C), 100% R.H. Environment.

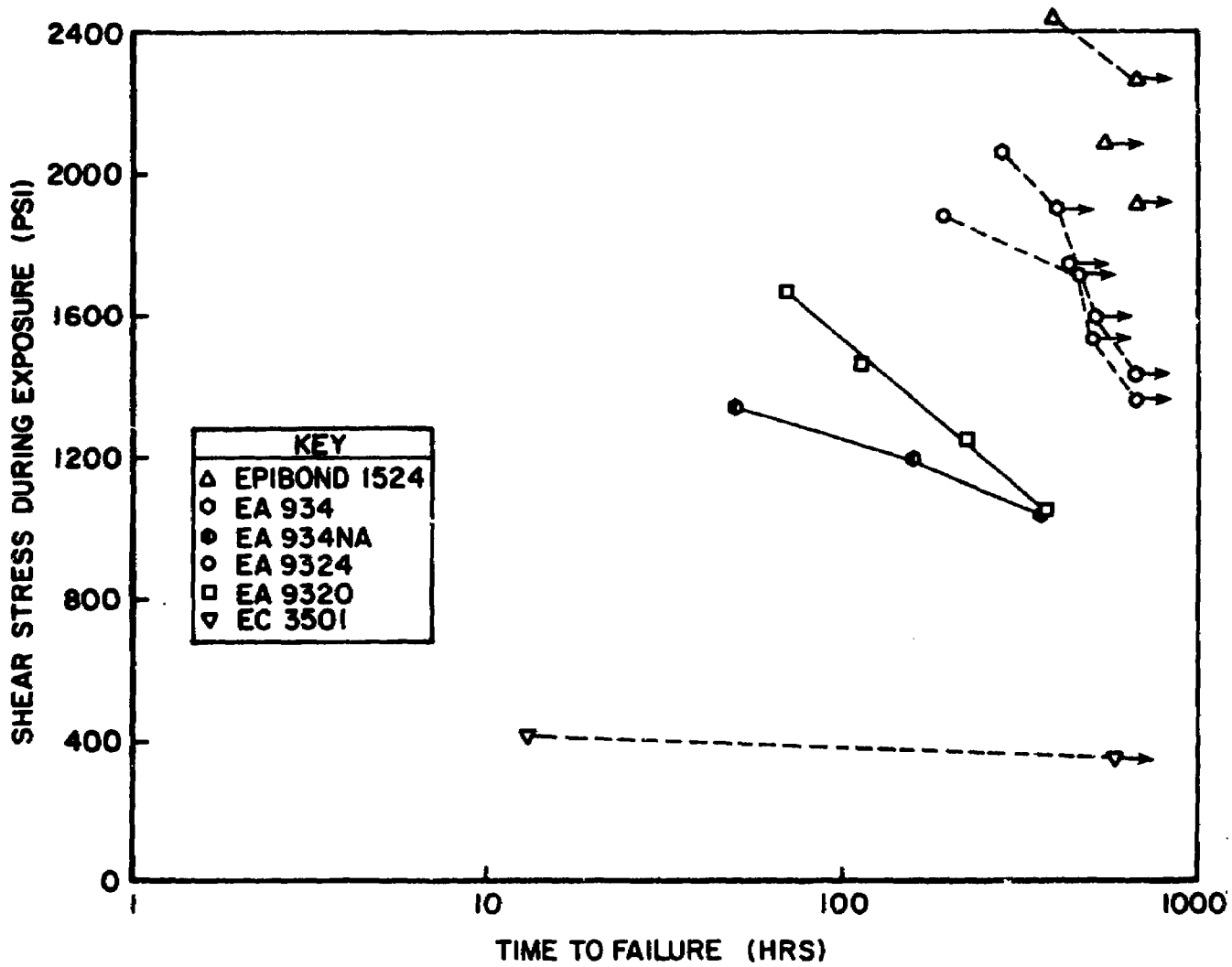


Figure 6. Stress-Durability Behavior on 6061T6 Bare Aluminum Adherends in a 140°F (60°C), 100% R.H. Environment.

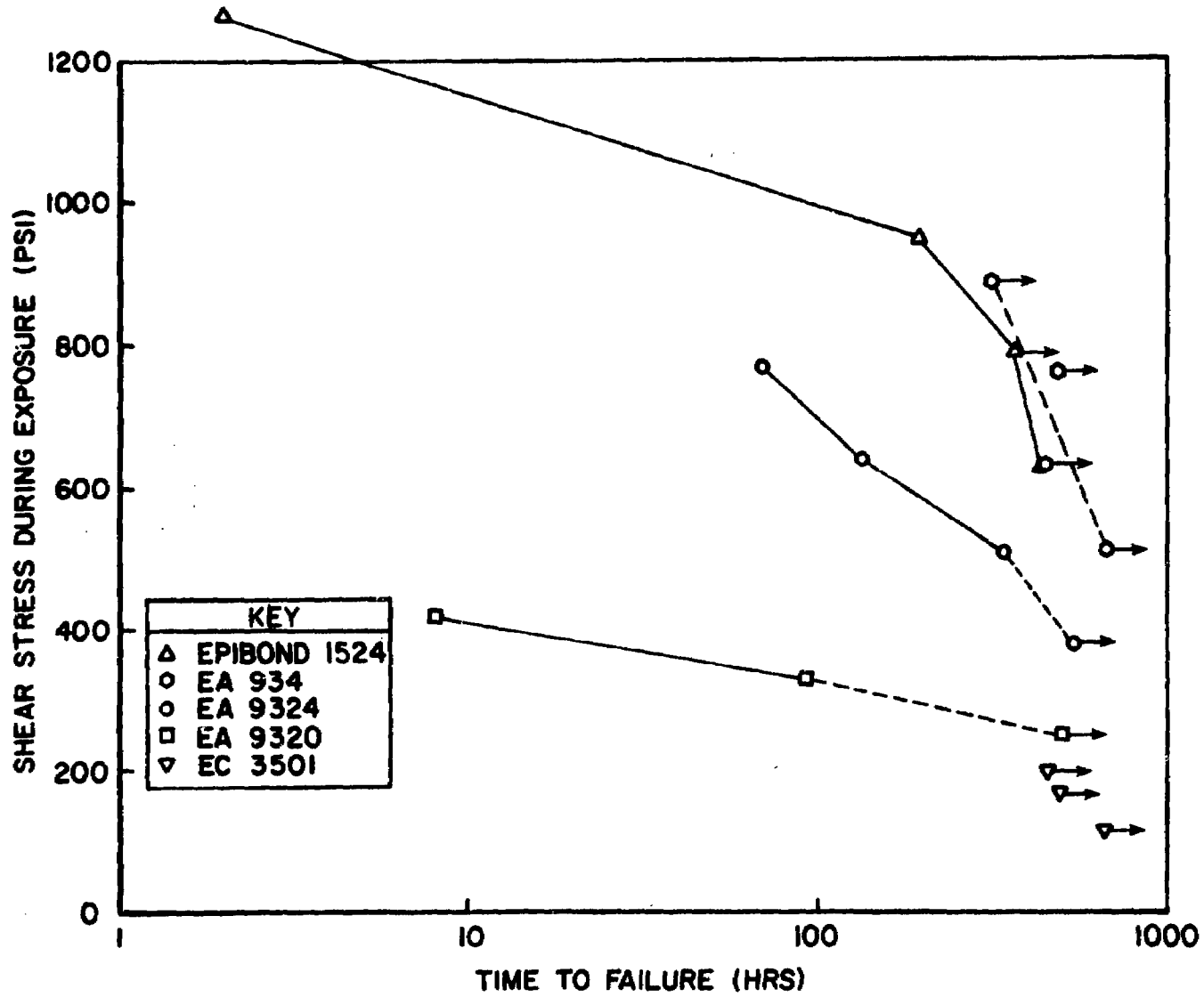


Figure 7. Stress-Durability Behavior on 5052H34 Bare Aluminum Adherends in a 200°F (93°C), 100% R.H. Environment.

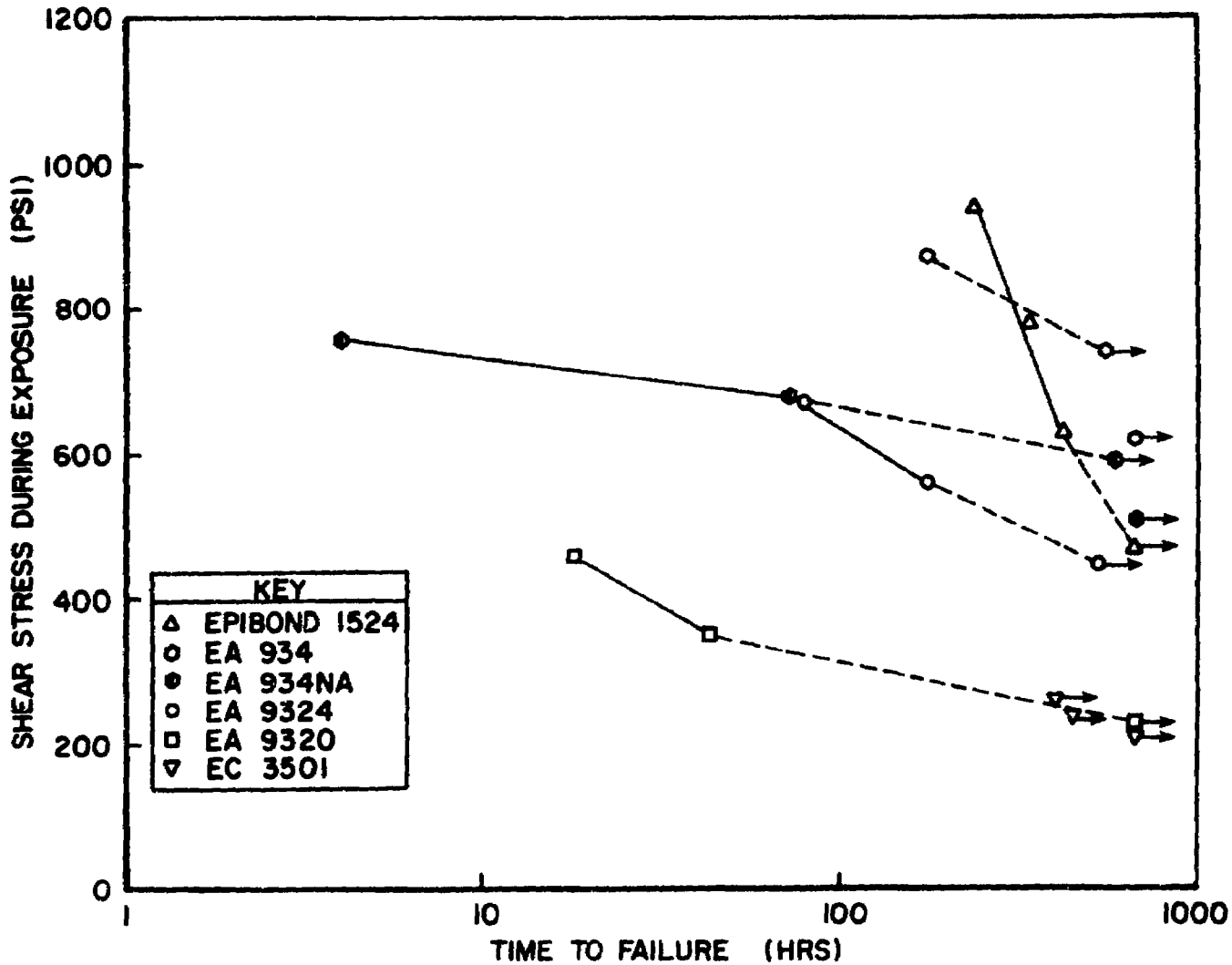


Figure 8. Stress-Durability Behavior on 6061T6 Bare Aluminum Adherends in a 200°F (93°C), 100% R.H. Environment.

behavior of the six adhesives tested. The EA934 and EA9324 materials are very similar and slightly lower than the Epibond 1524 performance. The EA9320 is somewhat lower than the EA934 and EA9324 performance levels. EA934NA is comparable to slightly lower than the EA9320 stress-durability performance in the 140°F (60°C) tests and the EC3501 is considerably lower than all of the other adhesives. This relative ranking is very similar to that obtained from the hot-wet lap shear agings discussed in the previous section.

The stress-durability results for the 200°F (93°C) exposure temperature (Figures 7 and 8) are similar but not identical to the 140°F (60°C) results. At this temperature, the EA934 adhesive is equivalent or slightly superior to the Epibond 1524 in its performance. The EA9324 is again somewhat lower than the top ranking adhesive(s) at this exposure temperature. At this temperature, however, the EA934NA adhesive ranks considerably higher that it did at the 140°F (60°C) exposure temperature. It compares very favorably with the EA9324 system on 6061T6 adherends at 200°F (93°C) and in the 500-600 psi (3.4-4.1 MPa) stress range even compares well with Epibond 1524. The EA9320 system fell well below the higher ranking adhesives at 200°F (93°C) in stress-durability performance and appeared to be equivalent to the EC3501 system in stress-durability at this temperature.

Examination of the failure modes of the specimens tested in this portion of the program does not reveal any consistent general patterns although a few isolated trends are noted. The EC3501 adhesive, for example, exhibits more interfacial adhesive-to-primer failure than cohesive failure within the adhesive layer on specimens which failed during the exposure period than on specimens which survived the exposure period and were tested for residual strength. In both cases the specimens failed predominantly within the adhesive layer, the difference being one of relative degree of interfacial vs. cohesive failure.

Comparison of the humidity aged lap shear failure modes with the stress-durability failure modes reveal that at 140°F (60°C), the lap shear tests produced much more adhesive-to-primer interfacial failure than the stress-durability tests. At 200°F (93°C) the difference in failure modes between the aged lap shear tests and the stress-durability tests is very slight, if present at all, and the failures for both the lap shear and stress-durability tests exhibit less interfacial adhesive-to-primer failure than the 140°F (60°C) lap shear specimens. This can most likely be ascribed to the relative amount of peel stress developed in the joint during testing. At high loads, single lap shear specimens made with 0.064 inch (0.16 cm) thick aluminum adherends develop substantial peeling stresses near the ends of the adherend overlap region. Since the stress-durability tests were conducted at loads which did not exceed 70 percent of the lap shear strength, the ratio of peel stress to shear stress was much lower in the stress-durability tests than in the lap shear tests. At 200°F (93°C) the loads needed to fail the lap shear specimens are sufficiently reduced that substantial peel stresses are not developed. Hence the failure modes observed in these tests not only reflect the relative resistance of each adhesive system to the effects of temperature and moisture, but also are influenced by the types of stresses introduced by specimen geometry.

As in Paragraph 3.1 for the lap shear results, an arbitrary rating system has been adopted in order to summarize the relative stress-durability performances of the adhesives tested in this investigation. Each adhesive was scored by awarding from 0 to 5 points to the adhesive based upon the location of its stress vs. time-to-failure curve (Figures 5-8) at three different times (200, 400, and 600 hours). These scores were totaled for each time and adherend alloy and an overall average score computed for each adhesive at each of the two exposure temperatures. Table 11 presents the scoring criteria for the stress-durability performances and Table 12 presents the scoring results.

TABLE 11

SCORING CRITERIA FOR STRESS-DURABILITY PERFORMANCE

Exposure Temperature	Position of Stress vs. Time-to-Failure Curves (psi)	(MPa)	Scoring Value
140°F(60°C)	over 2000	over 13.78	5
	1600-2000	11.02-13.78	4
	1200-1600	8.27-11.02	3
	800-1200	5.51-8.27	2
	400-800	2.76-5.51	1
	0-400	0-2.76	0
200°F(93°C)	over 1000	over 6.89	5
	800-1000	5.51-6.89	4
	600-800	4.13-5.51	3
	400-600	2.76-4.13	2
	200-400	1.38-2.76	1
	0-200	0-1.38	0

TABLE 12

ADHESIVE SCORES FOR STRESS-DURABILITY TESTS

Exposure Temp.	140°F (60°C)							200°F (93°C)						
Adherend Alloy	5052H34			6061T6			Overall 140°F	5052H34			6061T6			Overall 200°F
Time-to-Failure(hrs)	200	400	600	200	400	600	(60°C) Avg.Score	200	400	600	200	400	600	(93°C) Avg.Score
Adhesive														
EA9320	3	3	3*	3	2	2*	2.7	1	1	1*	1	1	1	1.0
EA9324	4	4	3	4	4	3	3.7	2	2	1*	2	2	2	1.8
EC3501	0	0	0	0	0	0	0	1*	1*	1*	1*	1*	1*	1.0
EA934	4*	4	3	5*	4	3	3.8	5	4	3	4	3	3	3.7
Epibond 1524	5	5	5	5*	5	5	5.0	4	3	2*	5*	3	2	3.2
EA934NA	---	---	---	2	2*	2*	2.0	---	---	---	3	3	2	2.7

*Estimated by extrapolation.

3.3 SUMMARY OF COMPARATIVE ADHESIVE SCORES FOR HOT-WET TESTS

The comparative scores developed for each adhesive with the arbitrary rating schemes described at the ends of Paragraphs 3.1 and 3.2 are summarized and illustrated in Table 13 and Figure 9. It must again be pointed out that only the data obtained from specimens which saw both elevated temperature and high humidity were used in developing these scores. In addition, no claim is made that some minimum score is required for an adhesive to perform acceptably in any particular application. These scores are only useful for comparing the relative merits of and ranking the adhesives tested in this program using a particular test specimen design. Other types of tests and other types of specimens may produce different relative rankings of these adhesives than was obtained here.

It is observed from the scores tabulated in Table 13 and plotted in Figure 9, that three adhesives (Epibond 1524, EA934, and EA9324) rank the highest of the six tested. Two (EA9320 and EA934NA) are grouped close to each other but are somewhat lower than the first three. The last adhesive (EC3501) ranks well below all of the others.

TABLE 13

COMPOSITE ADHESIVE SCORES FOR HOT-WET TESTS

Test Type	Lap Shear (ASTM D1002)		Stress-Durability (ASTM D2919)	
Exposure Condition	2 wks. at 140°F(60°C) & 100% RH/unstressed	2 wks. at 200°F(93°C) & 100% RH/stressed	140°F(60°C) & 100% RH/stressed	200°F(93°C) & 100% RH/stressed
Adhesive				
EA1524	4.5	4.5	5.0	3.2
EA934	5.0	3.0	3.8	3.7
EA9324	5.0	3.5	3.7	1.8
EA9320	5.0	1.0	2.7	1.0
EA934NA	3.0	2.0	2.0	2.7
EC3501	1.5	0	0	1.0

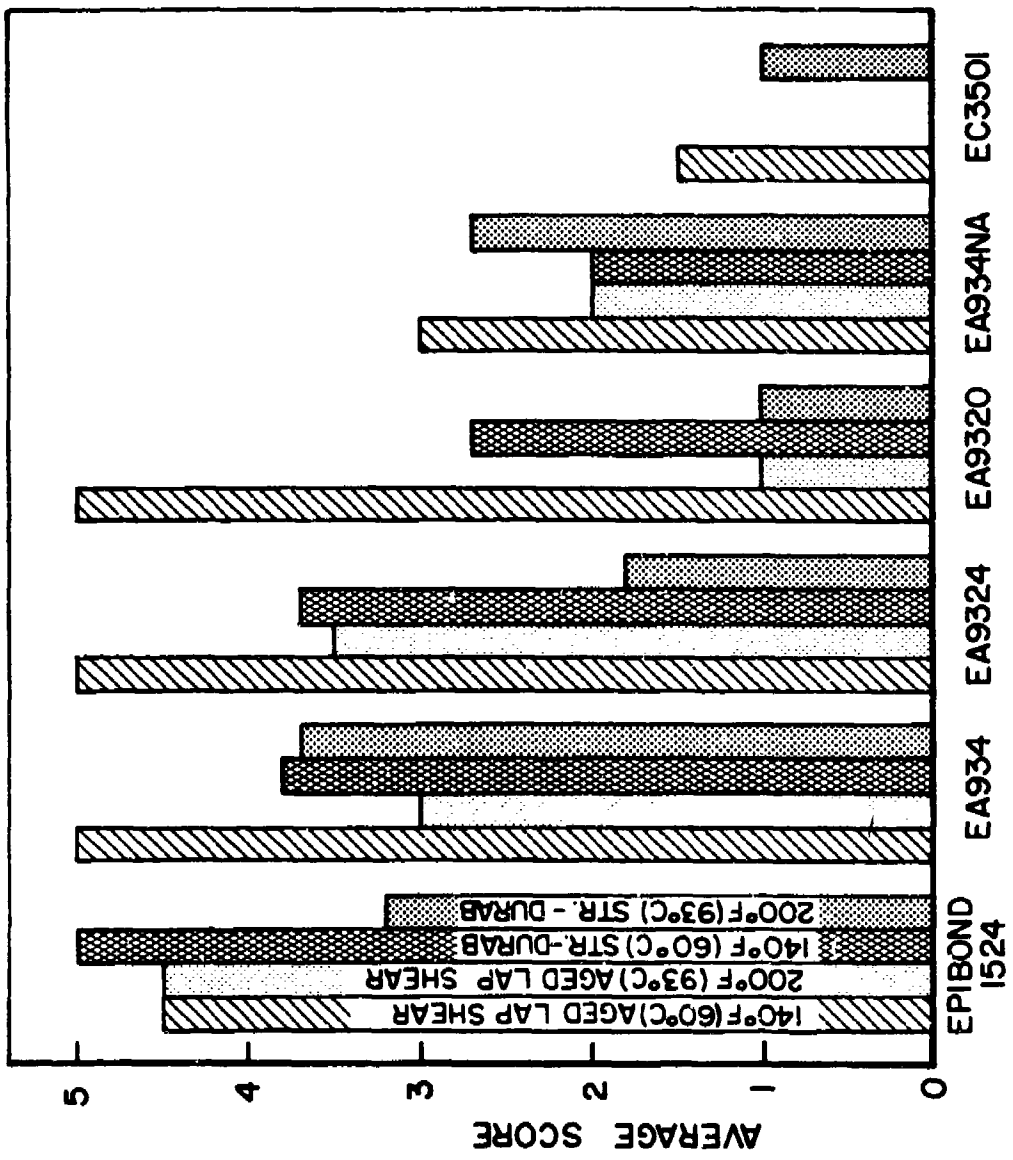


Figure 9. Average Adhesive Scores for Hot-Wet Tests.

SECTION 4
CONCLUSIONS

Lap shear and stress-durability tests were conducted on six different adhesives which are either used or are candidates for use as shelter repair adhesives. Five of these adhesives were tested on both 5052H34 and 6061T6 bare aluminum adherends and one was tested only on 6061T6 bare adherends. All adherends were given a phosphoric acid anodized surface treatment and primed with a corrosion inhibiting primer.

Three of the adhesives (Epibond 1524, EA934, and EA9324) withstood the combined elevated temperature, high humidity exposure conditions very well relative to the other three. Two of the adhesives (EA9320 and EA934NA) exhibited similar overall performance in the hot-wet exposure conditions but did not come up to the performance levels of the first three. One adhesive (EC3501) performed quite poorly relative to the other five.

APPENDIX A

ADHEREND SURFACE PREPARATION PROCEDURE

APPENDIX A

ADHEREND SURFACE PREPARATION PROCEDURE

A Phosphoric Acid Anodization (PAA) surface preparation method was used in this program. The step-by-step procedures utilized in this investigation for adherend surface preparation are described as follows.

Adherend Etch Procedure

1. Solvent wipe with MEK or acetone.
2. Vapor degrease for 10 minutes in trichloroethylene.
3. Alkaline wash for 10 minutes at 155 ± 5°F (68 ± 3°C) (Note 1).
4. Tap water rinse for 10 minutes in a continuous flow bath.
5. Etch for 10 minutes in an optimized FPL acid solution at 155 ± 5°F (68 ± 3°C) (Note 2).
6. Tap water rinse immediately after removal from etch solution for 10 minutes in an agitated continuous flow bath.
7. Anodize for 20 to 25 minutes in a phosphoric acid solution at 72 ± 5°F (22 ± 3°C) and 10 ± 1 volts D.C. (Note 3).
8. Tap water rinse immediately after power shut-off for 10 minutes in an agitated continuous flow bath.
9. Force dry with a heat gun or in an oven for 10 minutes at 150°F (66°C).

NOTES:

1 - Alkaline solution consists of:

(a) 1 gallon deionized water
(b) 170 grams Turco 4215
(c) 7 ml. Turco 4215 additive

2 - Optimized FPL acid solution consists of:

(a) 11.1 liters deionized water
(b) 417 grams Sodium Dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$)
(c) 2.0 liters Sulfuric Acid (H_2SO_4, reagent grade)
(d) 26 grams of dissolved 2024 aluminum alloy.

3 - Phosphoric Acid solution consists of:

(a) 1.0 liter deionized water
(b) 69 ml. of 85 percent Phosphoric Acid (H_3PO_4) or 85.5 ml. of 75 percent Phosphoric Acid (H_3PO_4)

The sodium dichromate and sulfuric acid concentrations of the FPL etch solution were checked daily and adjusted as needed according to the procedures outlined below. This frequency corresponded to an adjustment after etching about every 20 adherend panels.

Titration to Determine Sodium Dichromate Concentration of FPL Etch Solution

Materials:
- Sulfuric Acid, concentrated - 96.4 percent
- Potassium Iodide, crystals
- Sodium Thiosulfate, 0.1N (purchased)
- Starch Indicator Solution
- Deionized Water

All materials to be reagent grade.

Hardware:
- Mettler Balance
- Pipette: 1 ml, 1/100 ml graduations
- Pipette: 2 ml, 1/10 ml graduations
- Pipette: 5 ml, 1/10 ml graduations
- Pipette: 25 ml, 1/10 ml graduations
- Pipette: 50 ml Transfer
- Burets: 2 ea. 100 ml Automatic
- Burets: 1 ea. 50 ml Automatic
- Burets: 1 ea. 50 ml
- Magnetic Stirrer
- Magnetic Stir Bar
- 250 ml Ehrlenmeyer Flask
- Pipetting Bulb
- 250 or 500 ml Holding Bottles
- 125 ml Ehrlenmeyer Flask
- 1000 ml Ehrlenmeyer Flask
- 100 ml Volumetric Flask

Procedure:

1. Clean all glassware with Alconox and water, rinse several times with distilled or deionized water and allow to dry thoroughly.

2. Insure that glassware is at room temperature.

3. Make sulfuric acid, 10 percent, by weighing 100 grams of sulfuric acid (concentrated) into a flask (125 ml). Fill a 1000 ml flask with 500 grams of deionized water (weigh it). Pour the acid into the deionized water while stirring. Weigh additional deionized water into the flask until you have 1000 grams of solution.

4. Make 20 percent potassium iodide by weighing 20 grams into a 100 ml volumetric flask. Add a little bit of deionized water and swirl until the crystals dissolve. Add deionized water until the 100 ml volume mark is reached by the bottom of the meniscus. Store in a dark place -- it is light sensitive.

5. Pipette 2 ml of acid etch to be tested into a 250 ml Ehrlenmeyer flask. Drop a magnetic stir bar into the bottom and place on a stirrer.

6. Add 50 ml of deionized water by transfer pipette.

7. Add 12.5 ml of 10 percent H_2SO_4 (by pipette or buret).

8. Add 3 ml of potassium iodide [20 percent solution] (by pipette or buret).

9. Titrate with 0.1N sodium thiosulfate until a straw color appears -- do this very slowly so as not to overshoot the end-point (from buret).

10. Add 2 ml starch indicator by pipette.

11. While stirring rapidly, add 0.1N sodium thiosulfate dropwise very slowly until color changes to a light blue.

12. Record the number of ml of sodium thiosulfate used.

Calculations:

Determine the sodium concentration by the following formula:

$$\frac{\text{ml of sodium thiosulfate (0.1N) x 4.967}}{2} = \text{Sodium dichromate concentration in grams per liter of solution}$$

Safety:

Wear safety glasses, acid proof gloves, and a lab coat. Use Pipetting bulb for transferring liquids. Decontaminate spills with Alconox and water. For skin contact, wash thoroughly with soap and water. For eye contact, rinse 15 minutes with water, get medical aid.

Titration to Determine Sulfuric Acid Concentration of FPL Etch Solution

Materials:
- 0.1N NaOH Solution (purchased)
- Deionized Water

Hardware:

- Pipette: 1 ml, 1/100 ml graduations
- Pipetting Bulb
- 250 ml Beaker (2)
- Magnetic Stirrer
- 50 ml Transfer Pipette
- Magnetic Stir Bar
- pH Meter
- 100 ml Automatic Buret
- pH7 Buffer Solution

Procedure:

1. Clean all glassware with Alconox and water, dry thoroughly and bring to room temperature.
2. Place clean stir bar in a 250 ml beaker.
3. Transfer 0.5 ml of acid etch to the beaker using a 1.0 ml pipette.
4. Add 100 ml of deionized water using a transfer pipette.
5. Rinse pH meter electrodes with deionized water, wipe dry.
6. Immerse electrodes in buffer solution (pH7) and adjust meter to read pH7.
7. Rinse electrodes and wipe dry.
8. Immerse electrodes in the acid solution which you have placed on a stirrer.
9. Add NaOH (0.1N) dropwise until pH 3.5 is reached.
10. Record the number of ml on NaOH (0.1N) used.

Calculations:

Determine the sulfuric acid concentration as follows:

$$\frac{\text{ml of NaOH (0.1N)} \times 49.04}{5} = \text{Sulfuric acid concentration in grams per liter of solution}$$

Safety:

Wear safety glasses, acid proof gloves, and a lab coat. Pipette liquids using a bulb. Decontaminate spills with Alconox and water. For skin contact, wash thoroughly with soap and water. For eye contact, rinse 15 minutes with water, get medical aid.

Adjustment of FPL Etch

Materials:
- Sulfuric Acid (Reagent)
- Sodium Dichromate (Reagent)
- Deionized Water (needed only if measured concentrations are too high and solutions must be diluted)

Hardware:
- Graduated Cylinders - size as needed

Procedure:

1. After titration, the concentrations determine how much sodium dichromate and sulfuric acid to add using the following specification:

   Sodium Dichromate 28.5 grams/liter (27.0 - 30.0)
   Sulfuric Acid 285.0 grams/liter (280 - 290)

2. Adjust the acid first - remember adding acid changes the volume.

3. Add dichromate according to the new adjusted volume.

Calculations:

Example: Sodium dichromate was 21.5 grams/liter.
Sulfuric acid was 215 grams/liter.

To add acid 285-215 = 70 grams per liter

$$\frac{70}{1.65} = 42.4 \text{ ml of acid}$$

(10 percent sulfuric acid has specific gravity of 1.65 grams/ml)

(pour acid slowly - it will get hot as you add it to the solution)

The new volume is now 1.04 liters.

To add sodium dichromate

28.5-21.5 = 7 grams/liter
7 x 1.04 = 7.28 grams

After adjustment, recheck concentrations by titration.

If the concentrations measured by titration are too high, the reverse procedure (add water to dilute) must be followed.

Safety:

Acid gloves and aprons, safety glasses. Spills decontaminate with Alconox and water. Rinse skin or eyes with water - get medical aid.

The phosphoric acid anodizing solution was periodically discarded and a fresh solution used. The guidelines for this were visual and consisted of observation of the steel electrodes and the solution color. Whenever the electrodes first exhibited slight yellowish deposits of smut and the solution color changed from clear to slightly yellow, the phosphoric acid solution was discarded and a fresh batch charged into the tank.

As stated in Paragraph 2.1, the adherence surface preparation procedures detailed in the preceeding paragraphs are in general accordance with ARP 1524 (Aerospace Recommended Practice Number 1524 as proposed for adoption by the Society of Automotive Engineers in 1977). This procedure closely follows the PAA process developed earlier by Boeing. Our procedures do, however, differ slightly from those specified in ARP 1524. Table A-1 itemizes the sequential differences between the procedures followed in this investigation and those specified in ARP 1524.

TABLE A-1

DIFFERENCES BETWEEN SURFACE PREPARATION PROCEDURES USED BY UDRI IN THIS INVESTIGATION AND THOSE SPECIFIED IN ARP 1524

UDRI	ARP 1524
Solvent wipe w/MEK or acetone	No solvent wipe
Vapor degrease for 10 minutes in Trichloroethylene	Chlorosolv or vapor degrease w/1,1,1 Trichloroethane
Alkaline wash for 10 minutes at 155±5°F(68±3°C)	Same alkaline wash for 10-15 minutes at 150±5°F (65±3°C)
Tap water rinse for 10 minutes in a continuous flow bath at tap water temperature.	Tap water rinse 2 minutes minimum at 65-110°F (18-43°C) and 5 minutes minimum at 100-140°F (38-60°C)
Deoxidize for 10 minutes in an optimized FPL acid solution at 155±5°F (68±3°C)	Deoxidize with Amchem #6-16 for 10-15 minutes at R.T.
Tap water rinse immediately after removal from etch solution for 10 minutes in an agitated continuous flow bath.	Tap water rinse 2 minutes minimum at 65-110°F (18-43°C) and sprayed w/R.T. deionized water to remove tap water.
Anodize for 20-20 minutes in a phosphoric acid solution at 72±5°F (22±3°C) and 10±1 volt D.C.	Same as UDRI
Tap water rinse immediately after power shutdown for 10 minutes in an agitated continuous flow bath.	Tap water rinse within 2 minutes of power shutdown for 10-15 minutes in an agitated and overflowing bath and R.T. deionized water spray to remove tap water.
Force dry with a heat gun or in an oven for 10 minutes at 150°F (66°C).	Oven dry 30 minutes minimum at 175°F (80°C) maximum.
Cool to R.T. and prime within 2 hours.	Cool to R.T. and prime within 2 hours.

APPENDIX B

PRIMER APPLICATION PROCEDURE

APPENDIX B
PRIMER APPLICATION PROCEDURE

The primer was applied to the anodized adherends using the following equipment and procedures.

B.1 EQUIPMENT

A Brinks Wren B (air brush) was used in priming the panels.

A Dermitron D-9 (Eddy Current) by Unit Process Assemblies Inc. was used to measure primer thickness.

B.2 APPLICATION PROCEDURE

The primer was applied in several coats rather than in a one or two pass build up of primer thickness. The Brinks Wren B (air brush) was set up for best spray pattern using 20-25 psi line pressure and the primer was applied in 10 to 15 passes at a distance of 8 inches (20 cm).

Thickness measurements were taken with the Dermitron D-9 instrument several times during the course of the primer application until the desired primer thickness had been attained. The color of the primed surface was noted and the remainder of the panels were sprayed to visual color equivalence. All primed surfaces were inspected with the Dermitron D-9 Instrument to insure that the primer layer was within the desired thickness limits. Any primed surfaces with visibly obvious defects, blemishes, or incorrect primer thickness were rejected.

B.3 CURE CYCLE

Air dry for 30 minutes at 72°F (22°C)

100 percent check of primer thickness (manufacturers specification)

Force dry for 60 minutes at 250°F (121°C)

Spot check for primer thickness

B.4 STORAGE

The primed adherends were covered with Kimwipes and stored at 72°F (22°C), 50 percent relative humidity until bonding.

B.5 BONDING

The panels were bonded within 24 hours of priming using the manufacturers recommended cure cycle.

APPENDIX C

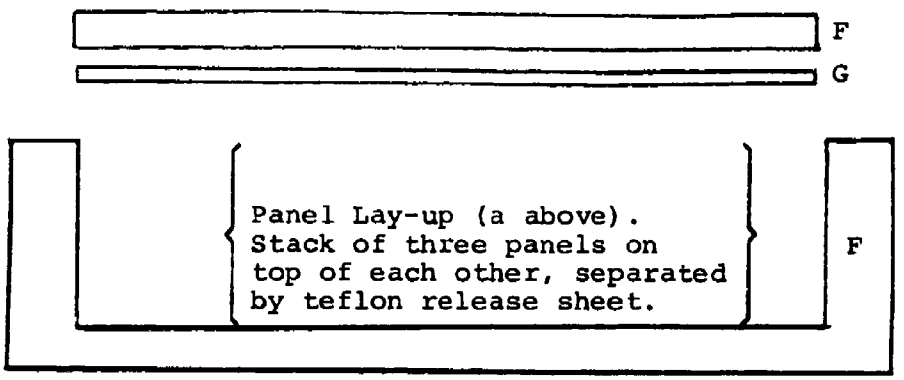
PANEL LAY-UP AND BONDING PROCEDURES

APPENDIX C
PANEL LAY-UP AND BONDING PROCEDURES

The adhesives were stored in their shipping containers at room temperature prior to use. The appropriate amounts of each component were hand blended on a clean flat surface with a steel spatula until color homogeneity was achieved. The adhesive paste was then trowelled onto the primed bond area by hand to an approximate thickness of 0.010-0.015 inch (0.254-0.381 mm) and the lay-up stack assembled as shown in Figure C-1.

A 20 pound (9 kg) weight was placed on the mold lid. This load corresponded to a bondline pressure of 4.4 lb/in^2 (30 kPA), based on a panel bondline area of 9 inches x 0.5 inch (22.9 cm x 1.3 cm). The mold was then left at room temperature for 24 hours under this load. After 24 hours the bonded panels were removed from the mold and kept at room temperature for six additional days before specimen machining was undertaken, for a total cure of seven days at room temperature.

(a) Lap-Shear Panel Lay-up Model



(b) Lay-up Stack

A - 5 mil teflon release sheet

B - aluminum spacer (thickness of panel adherend)

C - panel adherend

D - 5 mil teflon shim (for glueline thickness control)

E - adhesive (trowelled on paste)

F - lap shear mold (dimensioned to insure that when adherends are butted against sides of mold, overlap distance will be 0.500 inch)

G - 1/8 inch silicone rubber sheet

Figure C-1. Bonded Panel Lay-up Models.

APPENDIX D

SPECIMEN MACHINING PROCEDURES

APPENDIX D
SPECIMEN MACHINING PROCEDURES

There were two types of specimens employed in this program: those used in the static lap shear tests and those used in the stress-durability tests. The only difference between these two types of specimen is that the stress-durability specimens are 2 inches (5.1 cm) longer and have a hole in each end. Both were layed up in panel form as illustrated in Figure C-1 with seven specimens obtained from each panel. All seven specimens were finish-cut simultaneously from a panel on a gang mill using circular mill blades spaced one inch apart. During the milling operation the panels were clamped firmly in place in a special fixture to support the bondline during cutting and eliminate vibration damage. The clamping fixture is slotted to accommodate the mill blades. After milling, the hole position on the stress durability specimen was located by hand measurement and drilled to accommodate the gripping bolt in the spring fixture.

APPENDIX E

ADHESIVE PROPERTY
DATA FROM MANUFACTURERS' LITERATURE

APPENDIX E
ADHESIVE PROPERTY
DATA FROM MANUFACTURERS' LITERATURE

Hysol EA 9320

2024-T3 Clad, etch and primer not specified
Cure cycle: 7 days @ 75°F, (24°C), 10 psi (69 MPa)

Lap Shear: Exposure Condition	Test Temp	Strength psi	Strength MPa
None	R.T.	4680	32.2
None	180°F (82°C)	2330	16.1
None	-69°F (-55°C)	4040	27.8
30 Days @ 120°F (48°C) 95-100% R.H.	R.T.	4650	32.0
30 Days @ 120°F (48°C) 95-100% R.H.	180°F (82°C)	1890	13.0

Shelf Life: 1 year + at R.T.

Pot Life: 25-30 minutes at R.T.

Hysol EA 9324

2024-T3 Clad, chromic acid etch, primer not specified
Cure Cycle: 7 days @ 75°F (24°C), psi not specified

Lap Shear: Exposure Condition	Test Temp.	Strength psi	Strength MPa
None	-67°F (-55°C)	3000	20.6
None	R.T.	3200	22.0
None	180°F (82°C)	2800	19.3
30 days @ 120°F (49°C) 97% R.H.	R.T.	3600	24.8
None	180°F (82°C)	2250	15.5

Shelf Life: 1 year + at R.T.

Pot Life: 35-40 minutes at R.T.

3M EC 3501

3003 M-14, Abraded, no primer
Cure Cycle: 2 days, 75°F (24°C) 3-5 psi

Lap Shear: Exposure Condition	Test Temp	Strength psi	Strength MPa
None	-40°F (-55°C)	1065	7.3
None	R.T.	2100	14.5
None	180°F (82°C)	240	1.7

Shelf Life: Not Given

Pot Life: 7 minutes at R.T.

Hysol EA 934

2024 T-3 Clad, Chromic Acid Etch, Primer not specified
Cure Cycle: 2 days @ 75°F (24°C) 3-5 psi

Lap Shear: Exposure Condition	Test Temp.	Strength psi	MPa
None	-67°F (-55°C)	2600	17.9
None	R.T.	3100	21.4
None	180°F (82°C)	2200	15.2
None	200°F (93°C)	1800	12.4
30 days @ 120°F (49°C) 95-100% R.H.	120°F (49°C)	2900	20.0

Shelf Life: 2 years + at 0°F (-18°C) 2 mon. at 100°F (38°C)

Pot Life: 40 minutes at R.T.

Furane E-1524

2024 T-3 Clad, etch and primer not specified
Cure cycle: 2 hrs., 260°F (127°C), 200 psi

Lap Shear: Exposure Condition	Test Temp.	Strength psi	MPa
None	-67°F (-55°C)	3070	21.2
None	180°F (82°C)	4250	28.9
None	R.T.	3620	25.0
30 days @ 120°F (49°C) 95-100% R.H.	120°F (49°C)	3050	21.0

Hysol EA 934 NA

2024 T-3 Clad, chromic acid etch no primer
Cure Cycle: 6 hrs. at R.T., no psi

Lap Shear: Exposure Condition	Test Temp	Strength psi	MPa
None	-67°F (-55°C)	2750	19.2
None	R.T.	3575	24.6
None	300°F (149°C)	1455	10.0

Shelf Life: 2 years at 0°F (-18°C), 2 months at 100°F (38°C)

Pot Life: 40 minutes at R.T.

Adhesive Property Data
from Manufacturers Literature
for EC 2216 and EC 2054 Adhesives

3M EC 2216

Etched Aluminum, etch not specified
Cure cycle: 7 days @ 75°F, 2 psi

Lap Shear: Exposure Condition	Test Temp.	Strength psi	Strength MPa
None	-67°F (-55°C)	2000	13.8
None	75°F (24°C)	2500	17.2
None	180°F (82°C)	400	2.8
30 Days @ 120°F (48°C) 100% R.H.	75°F (24°C)	1985	13.7

Shelf Life: not given

Pot Life: 90 minutes at R.T.

3M EC 2054

Etched aluminum, etch not specified
Cure cycle: 7 days @ 75°F, 2 psi

Lap Shear: Exposure Condition	Test Temp.	Strength psi	Strength MPa
None	-67°F (-55°C)	1500	10.3
None	75°F (24°C)	2000	13.8
None	180°F (82°C)	400	2.8
30 Days @ 120°F (48°C), 100% R.H.	75°F (24°C)	1720	11.9

Shelf Life: not given

Pot Life: 60 minutes at R.T.

APPENDIX F

INDIVIDUAL SPECIMEN LAP-SHEAR DATA

TABLE F-1

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 6061-T6 ADHERENDS AT -65°F (-54°C)

ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa	
EA 9320	5150	35.5	10-0-90-0
	5200	35.8	10-10-80-0
	4080	28.1	20-10-70-0
Ave.	4810	33.1	10-10-80-0
S.D.	633	4.3	
EA 9324	2650	18.3	0-0-100-0
	2660	18.3	0-0-100-0
	2520	17.4	0-0-100-0
	2310	15.9	0-0-100-0
Ave.	2530	17.4	0-0-100-0
S.D.	163	1.1	
EC 3501	220	1.5	0-0-100-0
	210	1.5	0-0-100-0
	240	1.7	0-0-100-0
Ave.	220	1.5	0-0-100-0
S.D.	15	0.1	
EA 934	2400	16.5	0-0-100-0
	2420	16.7	0-0-100-0
	2930	20.2	0-10-90-0
Ave.	2590	17.9	0-0-100-0
S.D.	300	2.1	
Epibond 1524	1720	11.9	0-0-100-0
	1220	8.4	0-0-100-0
	1550	10.7	0-0-100-0
Ave.	1500	10.3	0-0-100-0
S.D.	254	1.8	
EA 934NA	2950	20.3	0-10-90-0
	2935	20.2	0-0-0-100
	3465	23.9	0-0-0-100
	3135	21.6	0-0-0-100
	3170	21.8	0-10-90-0
Ave.	3130	21.6	0-5-95-0
S.D.	215	1.5	

ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa	

[1]See Figure 2.

TABLE F-2

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 6061-T6 ADHERENDS AT ROOM TEMPERATURE

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	4790	33.0	10-10-70-10				
	4910	33.8	10- 0-80-10				
	4950	34.1	10- 0-70-20				
	4930	34.0	10- 0-70-20				
	5050	34.8	10- 0-70-20				
Ave.	4930	34.0	10- 0-70-20				
S.D.	93	0.6					
EA 9324	3920	27.0	0-0-80-20				
	3040	21.0	0-0-80-20				
	3750	25.8	0-0-80-20				
	4150	28.6	0-0-50-50				
	3710	25.6	0-0-50-50				
Ave.	3710	25.6	0-0-70-30				
S.D.	416	2.9					
EC 3501	2810	19.4	0-0-100-0				
	2730	18.8	0-0-100-0				
	2110	14.5	0-0-100-0				
	590	4.1	0-0-100-0				
	1700	11.7	0-0-100-0				
Ave.	1990	13.7	0-0-100-0				
S.D.	906	6.2					
EA 934	3790	26.1	0-0-90-10				
	3480	24.0	0-0-100-0				
	3350	23.1	0-0-80-20				
	3690	25.4	0-0-90-10				
	2560	17.6	0-0-100-0				
Ave.	3370	23.2	0-0-90-10				
S.D.	488	3.4					
Epibond 1524	3850	26.5	0-0-70-30				
	3520	24.3	0-0-40-60				
	3470	23.9	0-0-70-30				
	3260	22.5	0-0-80-20				
	3980	27.4	0-0-70-30				
Ave.	3620	24.9	0-0-70-30				
S.D.	293	2.0					
EA 934 NA	3630	25.0	0-0-90-10				
	3410	23.5	0-0-30-70				
	3730	25.7	0-0-70-30				
	3780	26.0	0-20-70-10				
	4640	32.0	0-10-80-10				
Ave.	3840	26.5	0-5-70-25				
S.D.	470	3.2					

[1]See Figure 2.

TABLE F-3

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 6061-T6 ADHERENDS AT 140°F (60°C)

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	3810	26.3	0-0-0-100	Epibond 1524	3660	25.2	0-0-100-0
	3720	25.6	0-0-0-100		2650	18.3	0-0-90-10
	3870	26.7	0-0-0-100		2390	16.5	0-0-100-0
	3630	25.0	0-0-0-100		3730	25.7	0-0-90-10
	3800	26.2	0-0-0-100		4250	29.3	0-0-90-10
	3770	26.0	0-0-0-100		4230	29.2	0-0-50-50
	4770	32.9	0-0-0-100		2860	19.7	0-0-100-0
	4800	33.1	0-0-0-100		4010	27.6	0-0-80-20
	4660	32.1	0-0-0-100				
	4950	34.1	0-0-0-100	Ave.	3470	23.9	0-0-90-10
				S.D.	736	5.1	
Ave.	4180	28.8	0-0-0-100				
S.D.	539	3.7					
EA 9324	3300	22.7	0-0-0-100	EA 934NA	2725	18.8	0-0-20-80
	3080	21.2	0-0-0-100		3000	20.7	0-0-20-80
	3680	25.4	0-0-0-100		2795	19.3	0-0-30-70
	3520	24.3	0-0-0-100		3035	20.9	0-0-10-90
	3120	21.5	0-0-0-100		3340	23.0	0-0-20-80
	3390	23.4	0-0-0-100				
	3680	25.4	0-0-0-100	Ave.	2980	20.5	0-0-20-80
	3620	24.9	0-0-0-100	S.D.	240	1.7	
	3340	23.0	0-0-0-100				
	3390	23.4	0-0-0-100				
Ave.	3410	23.5	0-0-0-100				
S.D.	214	1.5					
EC 3501	1090	7.5	0-0-100-0				
	790	5.4	0-0-100-0				
	690	4.8	0-0-100-0				
	950	6.6	0-0-90-10				
	1080	7.4	0-0-40-60				
	1360	9.4	0-0-30-70				
	1370	9.4	0-0-60-40				
	1460	10.1	0-0-40-60				
	1380	9.5	0-0-60-40				
	1520	10.5	0-0-80-20				
Ave.	1170	8.1	0-0-70-30				
S.D.	290	2.0					
EA 934	3000	20.7	0-0-20-80				
	3130	21.6	0-0-90-10				
	3030	20.9	0-0-80-20				
	2990	20.6	0-0-60-40				
	3090	21.3	0-0-10-90				
	3060	21.1	0-0-10-90				
	3270	22.5	0-0-10-90				
	3400	23.4	0-0-10-90				
	3370	23.2	0-0-30-70				
	3370	23.2	0-0-10-90				
Ave.	3170	21.8	0-0-30-70				
S.D.	165	1.1					

[1] See Figure 2.

TABLE F-4

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 6061-T6 ADHERENDS AT 200°F (93°C)

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	1780	12.3	0-0-10-90	Epibond 1524	3580	24.7	10-10-20-60
	2040	14.1	0-0-0-100		3560	24.5	10-10-20-60
	2470	17.0	0-0-0-100		2980	20.5	0-0-80-20
	2670	18.4	0-0-0-100		3010	20.7	0-0-90-10
	3130	21.6	0-0-0-100		2850	19.6	0-0-30-70
	2270	15.6	0-0-10-90		2700	18.6	10-0-70-20
	2280	15.7	0-0-10-90		3710	25.6	10-10-50-30
	2210	15.2	0-0-10-90		3120	21.5	0-10-70-20
	2220	15.3	0-0-10-90		2690	18.5	0-0-10-90
	1880	13.0	0-0-20-80				
Ave.	2300	15.9	0-0-10-90	Ave.	3130	21.6	5-5-65-25
S.D.	392	2.7		S.D.	390	2.3	
EA 9324	2010	13.9	0-0-0-100	EA 934NA	1680	11.6	0-0-20-80
	2020	13.9	0-0-0-100		1685	11.6	0-0-20-80
	2580	17.8	0-0-0-100		1585	10.9	0-0-30-70
	2140	14.7	0-0-0-100		1565	10.8	0-0-30-70
	2080	14.3	0-0-0-100		1969	13.5	0-0-20-80
	2540	17.5	0-0-0-100				
	1960	13.5	0-0-0-100	Ave.	1695	11.7	0-0-25-75
	2830	19.5	0-0-0-100	S.D.	158	1.1	
	2000	13.8	0-0-0-100				
	2200	15.2	0-0-0-100				
Ave.	2240	15.4	0-0-0-100				
S.D.	303	2.1					
EC 3501	290	2.0	0-0-90-10				
	220	1.5	0-0-90-10				
	330	2.3	0-0-80-20				
	440	3.0	0-0-50-50				
	670	4.6	0-0-20-80				
	630	4.3	0-0-10-90				
	680	4.7	0-0-10-90				
	340	2.3	0-0-20-70				
	620	4.3	0-0-70-30				
	440	3.0	0-0-0-100				
Ave.	470	3.2	0-0-40-60				
S.D.	172	1.2					
EA 934	2480	17.1	0-0-20-80				
	1960	13.5	0-0-70-30				
	2530	17.4	0-0-20-80				
	2560	17.6	0-0-20-80				
	2390	16.5	0-0-20-80				
	2130	14.7	0-0-10-90				
	2670	18.4	0-0-10-90				
	2380	16.4	0-0-10-90				
	2800	19.3	0-0-20-80				
	2940	20.3	0-0-60-40				
Ave.	2480	17.1	0-0-25-75				
S.D.	292	2.0					

[1]See Figure 2.

TABLE F-5

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 5052-H34 ADHERENDS AT -67°F (-54°C)

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	4160	28.7	0-0-100-0				
	4230	29.2	0-0-100-0				
	4580	31.6	10-0-80-10				
	3640	25.1	0-0-90-10				
	3970	27.4	40-0-40-20				
Ave.	4120	28.4	10-0-80-10				
S.D.	346	2.4					
EA 9324	2030	14.0	0-0-100-0				
	21 0	14.7	0-0-100-0				
	2190	15.1	0-0-100-0				
	2330	16.1	0-0-100-0				
Ave.	2170	15.0	0-0-100-0				
S.D.	125	0.9					
EC 3501	240	1.7	0-0-100-0				
	320	2.2	0-0-100-0				
	240	1.7	0-0-100-0				
Ave.	270	1.9	0-0-100-0				
S.D.	46	0.3					
EA 934	3260	22.5	0-0-100-0				
	2320	16.0	0-0-100-0				
	2000	13.8	0-0-100-0				
	2270	15.6	0-0-100-0				
	1820	12.5	0-0-100-0				
Ave.	2330	16.1	0-0-100-0				
S.D.	556	3.8					
Epibond 1524	2750	19.0	0-0-100-0				
	2650	18.3	0-0-100-0				
	2630	18.1	0-0-100-0				
Ave.	2680	18.5	0-0-100-0				
S.D.	64	0.4					

[1]See Figure 2.

TABLE F-6

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 5052-H34 ADHERENDS AT ROOM TEMPERATURE

ADHESIVE	STRENGTH		FAILURE MODE [1]	ADHESIVE	STRENGTH		FAILURE MODE [1]
	psi	MPa			psi	MPa	
EA 9320	4490	30.9	0-0-90-10				
	4750	32.7	0-0-80-20				
	4270	29.4	0-0-80-20				
	4050	27.9	0-0-80-20				
	4040	27.8	0-0-80-20				
Ave.	4320	29.7	0-0-80-20				
S.D.	303	2.1					
EA 9324	3410	23.5	0-0-80-20				
	3910	26.9	0-0-80-20				
	3160	21.8	0-0-90-10				
	3610	24.9	0-0-90-10				
	3630	25.0	0-0-80-20				
Ave.	3540	24.4	0-0-80-20				
S.D.	279	1.9					
EC 3501	2740	18.9	0-0-100-0				
	2550	17.6	0-0-90-10				
	2560	17.6	0-0-90-10				
	1750	12.1	0-0-100-0				
	1560	10.8	0-0-100-0				
Ave.	2230	15.4	0-0-90-10				
S.D.	536	3.7					
EA 934	3980	27.4	0-0-100-0				
	3370	23.2	0-0-100-0				
	3430	23.6	0-0-100-0				
	3010	20.7	0-0-100-0				
	3060	21.1	0-0-100-0				
Ave.	3370	23.2	0-0-100-0				
S.D.	388	3.0					
Epibond 1524	3600	24.8	0-0-100-0				
	4600	31.7	0-0-100-0				
	4300	29.6	0-0-100-0				
	3620	24.9	0-0-100-0				
	3850	26.5	0-0-100-0				
Ave.	3990	27.5	0-0-100-0				
S.D.	441	3.0					

[1] See Figure 2.

TABLE F-7

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 5052-H34 ADHERENDS AT 140°F (60°C)

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
Ea 9320	2780	19.2	0-0-0-100	Epibond 1524	3460	23.8	0-0-90-10
	3060	21.1	0-0-0-100		3110	21.4	0-0-100-0
	3170	21.8	0-0-0-100		3170	21.8	0-0-100-0
	3310	22.8	0-0-0-100		3410	23.5	0-0-100-0
	3370	23.2	0-0-10-90		3910	26.9	0-0-90-10
	3930	26.4	0-0-0-100		3360	23.2	0-0-10-90
	3910	26.9	0-0-0-100		3410	23.5	0-0-100-0
	3930	27.1	0-0-0-100		2810	19.4	0-0-100-0
	3440	23.7	0-0-0-100		3290	22.7	0-0-50-50
					3520	24.3	0-0-70-30
Ave.	3420	23.6	0-0-0-100	Ave.	3350	23.1	0-0-80-20
S.D.	410	2.8		S.D.	288	2.0	
EA 9324	2970	20.5	0-0-0-100				
	3050	21.0	0-0-0-100				
	3170	21.8	0-0-80-20				
	3160	21.8	0-0-10-90				
	3170	21.8	0-0-0-100				
	3340	23.0	0-0-0-100				
	3370	23.2	0-0-0-100				
	3670	25.3	0-0-30-70				
	3370	23.2	0-0-0-100				
	3390	23.4	0-0-0-100				
Ave.	3270	22.5	0-0-10-90				
S.D.	203	1.4					
EC 3501	1020	7.0	0-0-10-90				
	1210	8.3	0-0-20-80				
	1070	7.4	0-0-60-40				
	1370	9.4	0-0-40-60				
	1480	10.2	0-0-90-10				
	1480	10.2	0-0-90-10				
	1450	10.0	0-0-80-20				
	1430	9.9	0-0-70-30				
Ave.	1310	9.1	0-0-60-40				
S.D.	188	1.3					
EA 934	3220	22.2	0-0-10-90				
	3120	21.5	0-0-80-20				
	3140	21.6	0-0-90-10				
	3010	20.7	0-0-40-60				
	3090	21.3	0-0-40-60				
	3640	25.1	0-0-10-90				
	3190	22.0	0-0-0-100				
	3440	23.7	0-0-50-50				
	3390	23.4	50-0-20-30				
	3520	24.3	0-0-10-90				
Ave.	3280	22.6	5-0-30-65				
S.D.	203	1.4					

[1] See Figure 2.

TABLE F-8

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 5052-H34 ADHERENDS AT 200°F (93°C)

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	1420	9.8	0-0-0-100	Epibond 1524	3530	24.3	0-0-20-80
	1990	13.7	0-0-10-90		3280	22.6	0-0-30-70
	2000	13.8	0-0-10-90		3780	26.1	0-0-10-90
	1850	12.8	0-0-20-80		3320	22.9	10-0-40-50
	1410	9.7	0-0-40-60		3400	23.4	0-0-0-100
	1270	8.8	0-0-40-60		3160	21.8	0-0-60-40
	1470	10.1	0-0-40-60		2450	16.9	0-0-80-20
	1280	8.9	0-0-50-50		2980	20.5	0-0-100-0
	2100	14.5	0-0-30-70		2810	19.4	0-0-90-10
	1890	13.0	0-0-40-60		2890	19.9	0-0-90-10
Ave.	1670	11.5	0-0-30-70	Ave.	3160	21.8	0-0-50-50
S.D.	326	2.2		S.D.	387	2.7	
EA 9324	2080	14.3	0-0-0-100				
	1980	13.6	0-0-0-100				
	2510	17.3	0-0-0-100				
	2180	15.0	0-0-0-100				
	2410	16.6	0-0-0-100				
	3000	20.7	0-0-0-100				
	2340	16.1	0-0-0-100				
	2960	20.4	0-0-0-100				
	2940	20.3	0-0-0-100				
	3180	21.9	0-0-0-100				
Ave.	2560	17.6	0-0-0-100				
S.D.	430	3.0					
EC 3501	430	3.0	0-0-0-100				
	550	3.8	0-0-0-100				
	570	3.9	0-0-0-100				
	690	4.8	0-0-10-90				
	500	3.5	0-0-10-90				
	630	4.3	0-0-10-90				
	640	4.4	0-0-10-90				
	610	4.2	0-0-10-90				
Ave.	580	4.0	0-0-10-90				
S.D.	84	0.6					
EA 934	2590	17.8	0-0-40-60				
	2510	17.3	0-0-50-50				
	2630	18.1	0-0-80-20				
	2430	16.7	0-0-20-80				
	2470	17.0	0-0-20-80				
	2040	14.1	0-0-10-90				
	2650	18.3	0-0-60-40				
	2670	18.4	0-0-40-60				
	2700	18.6	0-0-60-40				
	2660	18.3	0-0-40-60				
Ave.	2530	17.4	0-0-40-60				
S.D.	196	1.4					

[1]See Figure 2.

TABLE F-9

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES
ON 6061-T6 ADHERENDS AT 140°F (60°C)
AFTER 14 DAYS @ 140°F (60°C), 95-100% R.H.

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	3890	26.8	10-0-10-80				
	3880	26.7	0-0-10-90				
	3950	27.2	0-0-10-90				
	4170	28.7	0-0-10-90				
	3860	26.6	0-0-10-90				
Ave.	3950	27.2	0-0-10-90				
S.D.	127	0.9					
EA 9324	3800	26.2	0-0-10-90				
	3650	25.2	0-0-20-80				
	3760	25.9	0-0-20-80				
	3980	27.4	0-0-20-80				
	3890	26.8	0-0-10-90				
Ave.	3820	26.3	0-0-20-80				
S.D.	126	0.9					
EC 3501	590	4.1	0-0-0-100				
	570	3.9	0-0-0-100				
	550	3.8	0-0-10-90				
	1000	6.9	0-0-10-90				
	640	4.4	0-0-0-100				
Ave.	670	4.6	0-0-5-95				
S.D.	187	1.3					
EA 934	3550	24.5	0-10-10-80				
	3470	23.9	0-0-70-30				
	3600	24.8	0-0-70-30				
	3360	23.2	0-20-60-20				
	3550	24.5	0-20-30-50				
Ave.	3510	24.2	0-10-50-40				
S.D.	94	0.7					
Epibond 1524	3580	24.7	0-100-0-0				
	4550	31.4	0-90-10-0				
	2300	15.9	0-0-100-0				
	1490	10.3	0-0-90-10				
	2020	13.9	0-0-90-10				
Ave.	2790	19.2	0-40-55-5				
S.D.	1249	8.6					
EA 934NA	2335	16.1	0-0-20-80				
	2215	15.3	0-0-20-80				
	2275	15.7	0-0-30-70				
	2255	15.5	0-0-30-70				
	2520	17.4	0-0-20-80				
Ave.	2320	16.0	0-0-25-75				
S.D.	120	0.8					

[1]See Figure 2.

TABLE F-10

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES
ON 6061-T6 ADHERENDS AT 200°F (93°C)
AFTER 14 DAYS @ 200°F (93°C), 95-100 PERCENT R.H.

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	1700	11.7	0-0-50-50				
	1550	10.7	0-0-60-40				
	1600	11.0	0-0-70-30				
	1320	9.1	0-0-70-30				
	970	6.7	0-0-80-20				
Ave.	1430	9.8	0-0-70-30				
S.D.	291	2.0					
EA 9324	3040	22.3	0-0-10-90				
	3120	21.5	0-0-0-100				
	3120	21.5	0-0-0-100				
	2480	17.1	0-0-0-100				
	2710	18.7	0-0-10-90				
Ave.	2935	20.2	0-0-5-95				
S.D.	324	2.2					
EC 3501	480	3.3	0-0-10-90				
	280	1.9	0-0-60-40				
	330	2.3	0-0-20-80				
	590	4.1	0-0-10-90				
	570	3.9	0-0-10-90				
Ave.	450	3.1	0-0-20-80				
S.D.	140	1.0					
EA 934	2420	16.7	0-0-30-70				
	2270	15.6	0-0-40-60				
	2400	16.5	0-0-30-70				
	2390	16.5	0-0-40-60				
	2400	16.5	0-0-30-70				
Ave.	2370	16.3	0-0-30-70				
S.D.	62	0.4					
Epibond 1524	3190	22.0	0-10-40-50				
	3740	25.8	0-90-10-0				
	1150	7.9	0-0-60-40				
	3480	24.0	0-10-60-30				
	1400	9.7	0-0-70-30				
Ave.	2590	17.9	0-20-50-30				
S.D.	1221	8.4					
EA 934NA	1415	9.8	5-0-60-35				
	1580	10.9	0-0-60-40				
	1480	10.2	0-0-70-30				
	1610	11.1	0-0-60-40				
	1645	11.3	0-0-60-40				
Ave.	1545	10.7	0-0-65-35				
S.D.	95	0.7					

[1]See Figure 2.

TABLE F-11

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 5052-H34 ADHERENDS AT 140°F (60°C) AFTER 14 DAYS @ 140°F (60°C), 95-100% R.H.

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	4490	30.9	0-0-90-10				
	4750	32.7	0-0-80-20				
	4270	29.4	0-0-80-20				
	4050	27.9	0-0-80-20				
	4040	27.8	0-0-80-20				
Ave.	4320	29.7	0-0-80-20				
S.D.	303	2.1					
EA 9324	3410	23.5	0-0-80-20				
	3910	26.9	0-0-80-20				
	3160	21.8	0-0-90-10				
	3610	24.9	0-0-90-10				
	3630	25.0	0-0-80-20				
Ave.	3540	24.4	0-0-80-20				
S.D.	279	1.9					
EC 3501	540	3.7	0-0-10-90				
	510	3.5	0-0-10-90				
	460	3.2	0-0-10-90				
	670	4.6	0-0-10-90				
	620	4.3	0-0-10-90				
Ave.	560	3.9	0-0-10-90				
S.D.	85	0.6					
EA 934	3980	27.4	0-0-100-0				
	3370	23.2	0-0-100-0				
	3430	23.6	0-0-100-0				
	3010	21.1	0-0-100-0				
	3060	21.1	0-0-100-0				
Ave.	3370	23.2	0-0-100-0				
S.D.	388	2.7					
Epibond 1524	3600	24.8	0-0-100-0				
	4600	31.7	0-0-100-0				
	4300	29.6	0-0-100-0				
	3620	24.9	0-0-100-0				
	3850	26.5	0-0-100-0				
Ave.	3990	27.5	0-0-100-0				
S.D.	441	3.0					

[1] See Figure 2.

TABLE F-12

INDIVIDUAL LAP SHEAR TEST RESULTS FOR REPAIR ADHESIVES ON 5052-H34 ADHERENDS AT 200°F (93°C) AFTER 14 DAYS @ 200°F (93°C), 95-100% R.H.

ADHESIVE	STRENGTH		FAILURE MODE[1]	ADHESIVE	STRENGTH		FAILURE MODE[1]
	psi	MPa			psi	MPa	
EA 9320	990	6.8	0-0-60-40				
	1150	7.9	0-0-60-40				
	1210	8.3	0-0-40-60				
	1070	7.4	0-0-80-20				
	1220	8.4	0-0-60-40				
Ave.	1130	7.8	0-0-60-40				
S.D.	97	0.7					
EA 9324	2240	15.4	0-0-0-100				
	2230	15.4	0-0-0-100				
	2090	14.4	0-0-0-100				
	2730	18.8	0-0-0-100				
	2520	17.4	0-0-0-100				
Ave.	2360	16.3	0-0-0-100				
S.D.	258	1.8					
EC 3501	290	2.0	0-0-20-80				
	260	1.8	0-0-30-70				
	360	2.5	0-0-0-100				
	540	3.7	0-0-0-100				
	560	3.9	0-0-0-100				
Ave.	400	2.8	0-0-10-90				
S.D.	140	1.0					
EA 934	2370	16.3	0-0-40-60				
	2180	15.0	0-0-40-60				
	2400	16.5	0-0-50-50				
	2790	19.2	0-0-30-70				
	2300	16.6	0-0-30-70				
Ave.	2410	16.6	0-0-40-60				
S.D.	230	1.6					
Epibond 1524	3460	23.8	0-40-40-20				
	2740	18.9	0-20-60-20				
	2940	20.3	0-0-50-50				
	3100	21.4	10-10-40-40				
	3450	23.8	0-0-0-100				
Ave.	3140	21.6	0-20-40-40				
S.D.	316	2.2					

[1]See Figure 2.

APPENDIX G

INDIVIDUAL SPECIMEN STRESS-DURABILITY DATA

TABLE G-1

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 9320 ADHESIVE AT 140°F (60°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
40	107-6	1670	11.5	34			0-0-60-40	50	57-2	1710	11.8	14			0-0-40-60
	109-1			62			0-0-30-70		58-7	1710	11.8	14			0-0-50-50
	113-3			112			0-0-30-70		61-6	1710	11.8	12			0-0-20-80
				Avg. 69			0-0-40-60		63-3	1710	11.8	97			0-0-20-80
				S.D. 40					60-3			10			0-0-20-80
									64-7			205			0-0-40-60
35	110-6	1460	10.1	169			0-0-50-50		65-5			135			0-0-20-80
	114-3			131			0-0-40-60		66-6			69			0-0-30-70
	112-5			110			0-0-30-70					Avg. 70			0-0-30-70
	116-7			36			0-0-70-30					S.D. 72			
				Avg. 112			0-0-50-50								
				S.D. 56				45	57-6	1540	10.6	34			0-0-40-60
									58-5	1540	10.6	8			0-0-30-70
30	113-6	1250	8.6	163			0-0-40-60		59-5	1540	10.6	85			0-0-40-70
	115-6			107			0-0-60-40		60-1	1540	10.6	11			0-0-20-80
	111-2			304			0-0-30-70		62-5	1540	10.6	504			0-0-20-80
	107-4			358			0-0-40-60		61-2			10			0-0-20-80
	110-2			154			0-0-30-70		63-4			231			0-0-30-70
	114-4			170			0-0-30-70		64-5			94			0-0-20-80
	167-7			309			0-0-30-70		65-6			257			0-0-30-70
				Avg. 224			0-0-35-65					Avg. 137			0-0-30-70
				S.D. 97								S.D. 167			
								40	59-6	1370	9.4	148			0-0-60-40
25	167-4	1050	7.2	265			0-0-30-70		60-2			158			0-0-60-40
	108-4			357			0-0-30-70		61-7			115			0-0-40-60
	110-3			565			0-0-40-60		62-7			451			0-0-30-70
	112-3			599			0-0-50-50		63-5			672+	3140	21.6	10-0-30-60
	109-4			300			0-0-50-50		64-6			672+	3730	25.7	0-0-40-60
	113-4			178			0-0-40-60		65-7			427			0-0-50-50
	114-6			338			0-0-70-30		66-1			528			0-0-40-60
				Avg. 372			0-0-45-55		57-5			62			0-0-30-70
				S.D. 155					58-4			82			0-0-30-70
												Avg. >332	3435	23.7	0-0-40-60
												S.D. 245			

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-2

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 9324 ADHESIVE AT 140°F (60°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
55	123-6	1880	12.9	301			0-0-0-100	60	58-2	1960	13.5	13			0-0-0-100
	117-4			36			0-0-10-90		76-4			395			0-0-0-100
	118-7			32			0-0-10-90		76-1			155			0-0-0-100
	119-4			225			0-0-0-100					Avg. 188			0-0-0-100
	121-2			672+	4000	27.6	0-0-0-100					S.D. 193			
	124-7			63			0-0-0-100								
	168-1			38			0-0-0-100								
								50	67-2	1640	11.3	1			0-0-50-50
				Avg.>195			0-0-5-95		70-4			1			0-0-0-100
				S.D. 236					69-4			672+	3700	25.5	0-0-40-60
									71-2			603			0-0-10-90
50	124-5	1710	11.7	273			0-0-10-90		68-3			36			0-0-10-90
	117-5			672+	2650	18.3	0-0-0-100		72-3			370			0-0-0-100
	118-4			672+	5060	34.9	0-0-40-60		73-4			672+	3510	24.2	0-0-20-80
	120-3			346			0-0-0-100		74-7			657			0-0-0-100
	122-2			672+	3870	26.7	0-0-10-90					Avg. >376	3605	24.9	0-0-15-85
	123-4			470			0-0-0-100					S.D. 317			
	125-5			143			0-0-10-90								
				Avg.>464	3860	26.6	0-0-10-90	45	67-4	1470	10.1	672+	3480	24.0	0-0-40-60
				S.D. 217	1205	8.3			68-1			672+	3770	26.0	10-0-40-50
45	122-1	1530	10.6	565			0-0-10-90		70-2			11			0-0-0-100
	123-2			273			0-0-10-90		72-2			614			0-0-10-90
	120-1			672+	4060	28.0	0-0-20-80		74-6			422			0-0-40-60
	121-4			614			0-0-10-90		69-5			59			0-0-30-70
	124-6			310			0-0-10-90		70-1			672+	3140	21.6	0-0-10-90
	125-4			602			0-0-0-100		71-7			672+	3360	23.2	0-0-40-60
				Avg.>506			0-0-10-90					Avg. >474	3440	23.7	0-0-25-75
				S.D. 170								S.D. 284	263	1.8	
40	117-6	1360	9.4	672+	4940	34.0	0-0-30-70	40	71-6	1310	9.0	672+	3710	25.6	0-0-30-70
	118-3			672+	4510	31.2	0-0-40-60		72-1			672+	3490	24.1	0-0-40-60
	119-7			672+	4440	30.6	0-0-10-90		73-6			672+	3600	24.8	0-0-40-60
	121-1			672+	4160	28.7	0-10-10-80		74-5			672+	3830	26.4	0-0-40-60
									75-1			672+	3970	27.4	0-0-40-60
				Avg. >672	4520	31.1	0-0-25-75		76-5			672+	4100	28.3	0-0-40-60
				S.D. 0	320	2.2						Avg. >672	3780	26.1	0-0-40-60
												S.D. 0	229	1.6	

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-3

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 934 ADHESIVE AT 140°F (60°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
65	145-4	2060	14.2	284			0-0-30-70	55	161-3	1800	12.5	235			0-0-10-90
									162-1			155			0-0-20-80
				Avg. 284			0-0-30-70		87-6			392			0-0-30-70
				S.D. 0								Avg. 261			0-0-20-80
60	137-6	1900	13.1	57			0-0-20-80					S.D. 121			
	138-4			444			0-0-30-70								
	139-2			11			0-0-20-80	50	91-7	1640	11.3	672+	2790	19.2	0-0-90-10
	141-7			612			0-0-30-70		161-2			314			0-0-20-80
	142-1			433			0-0-20-80		93-3			518			10-0-20-70
	143-3			595			0-0-20-80		94-6			672+	3510	24.2	0-0-30-70
	140-5			672+	3120	21.5	0-0-40-60		95-1			638			0-0-10-90
				Avg. >403			0-0-25-75		89-6			394			0-0-40-60
				S.D. 268					90-3			637			0-0-30-70
												Avg. >549	3150	21.7	0-0-35-65
55	144-7	1740	12.0	156			0-10-30-60					S.D. 145			
	145-6			409			0-0-20-80								
	146-1			409			0-0-40-60	45	81-7	1480	10.2	672+	3270	22.5	0-0-60-40
	142-7			325			0-0-30-70		88-4			672+	3210	22.1	0-0-60-40
	141-3			658			0-0-10-90		89-7			204			0-0-60-40
	143-4			672+	3970	27.4	0-0-80-20		90-2			672+	3230	22.3	0-0-60-40
				Avg. >438			0-0-35-65		91-4			589			0-0-40-60
				S.D. 268					93-5			672+	2520	17.4	10-10-30-50
									94-4			672+	3000	20.7	0-0-30-70
50	142-2	1590	10.9	512			0-0-30-70					Avg. >593	3046	21.0	0-0-50-50
	143-2			608								S.D. 174	312	2.1	
	139-4			108			0-0-20-80	40	91-6	1310	9.0	672+	3360	23.2	0-0-90-10
	140-2			672+	3480	24.0	0-10-30-60		161-1			672+	3220	22.2	0-0-60-40
	144-4			672+	3600	24.8	0-0-40-60		93-6			672+	2820	19.4	0-0-60-40
									94-3			672+	3200	22.1	0-0-60-40
				Avg. >514	3540	24.4	0-0-30-70		95-6			672+	3700	25.5	0-0-70-30
				S.D. 236	85	0.6			162-4			672+	3160	21.8	0-0-40-60
45	141-6	1430	9.8	672+	3370	23.2	0-0-30-70								
				Avg. >672	3370	23.2	0-0-30-70					Avg. >672	3240	22.3	0-0-60-40
				S.D. 0	0	0						S.D. 0	287	2.0	

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-4

INDIVIDUAL STRESS-DURABILITY DATA WITH
EC 3501 ADHESIVE AT 140°F (60°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
35	131-7	410	2.8	2			0-0-70-30	30	159-4	393	2.7	2			0-0-40-60
	129-5			50			0-0-30-70		83-2			2			0-0-90-10
	143-4			12			0-0-30-70		83-1			2			0-0-50-50
	135-6			2			0-0-70-30		80-6			12			0-0-90-10
	109-3			12			0-0-50-50		86-1			1			0-0-80-20
	140-7			12			0-0-60-40								
	129-7			12			0-0-30-70					Ave. 3			0 0-70-30
	143-2			23			0-0-20-80					S.D. 4			
	135-3			1			0-0-70-30								
	171-7			1			0-0-40-60	25	77-5	328	2.3	10			0-0-80-20
									79-7			672+	1000	6.9	0-0-0-100
				Ave. 13			0-0-45-55		80-5			11			0-0-50-50
				S.D. 15					85-5			17			0-0-90-10
									82-3			672+	620	4.3	0-0-20-80
30	132-4	350	2.4	672+	800	5.5	0-0-20-80		157-6			82			0-0-20-80
	133-5			672+	790	5.4	0-0-10-90		84-7			106			0-0-30-70
	131-4			672+	740	5.1	0-0-10-90								
	171-4			672+	669	4.6	0-0-10-90					Avg. >224	810	5.6	0-0-40-60
	127-6			106			0-0-30-70					S.D. 308			
	127-4			672+	580	4.0	0-0-0-100								
	128-5			672+	840	5.8	0-0-0-100	20	64-6	262	1.8	3			0-0-60-40
									85-4			139			0-0-40-60
				Avg. >591	735	5.1	0-0-10-90		86-7			672+	840	5.8	0-0-10-90
				S.D. 214	98	0.6			81-1			395			0-0-50-50
									160-5			70			0-0-30-70
									81-6			672+	670	4.3	0-0-10-90
									82-5			12			0-0-80-20
									83-3			672+	700	4.8	0-0-10-90
									65-6			58			0-0-50-50
												Avg. > 299	737	5.0	0-0-30-70
												S.D. 302	91	0.8	

[1]The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature

[2]See Figure 2.

TABLE G-5

INDIVIDUAL STRESS-DURABILITY DATA WITH EPIBOND 1524 ADHESIVE AT 140°F (60°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
70	172-5	2430	16.7	395			0-0-20-80	70	102-7	2350	16.2	250			0-0-80-20
				Avg. 395			0-0-20-80					Avg. 250			0-0-80-20
65	155-3	2260	15.6	672+	4220	29.1	0-30-60-10	60	104-3	2010	13.9	672+	3690	25.4	0-0-100-0
	172-2			672+	4730	32.6	0-0-80-20					Avg.>672	3690	25.4	0-0-100-0
				Avg.>672	4475	30.8	0-15-70-15								
								50	104-4	1680	11.6	672+	3610	24.9	0-10-80-10
60	147-5	2080	14.4	625			0-0-50-50		106-2			672+	3880	26.7	0-0-90-10
	149-5			382			0-20-60-20		165-5			672+	3330	22.9	0-30-40-30
	151-2			672+	4050	27.9	0-0-100-0		163-4			672+	3160	21.8	0-0-80-20
				Avg.>550			0-10-55-35		164-2			672+	3180	21.9	0-60-20-20
				S.D. 156								Avg.>672	3430	23.6	0-20-60-20
												S.D. 0	308	2.1	
55	151-3	1910	13.2	672+	4150	28.6	10-70-10-10								
	156-6			672+	3750	25.8	0-20-70-10	55	98-4	1840	12.7	672+	3540	24.4	0-30-50-10
	154-3			672+	3800	26.2	0-0-80-20					Avg.>672	3540	24.4	0-30-50-10
				Avg.>672	3900	26.9	0-30-55-15								
				S.D. 0	218	1.5									

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-6

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 934 NA ADHESIVE AT 140°F (60°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level (%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
45	181-6	1340	9.2	70			0-0-20-80								
	182B-1			132			0-0-10-90								
	182C-2			10			0-0-0-100								
	1-1			13			0-0-0-100								
				Avg. 50			0-0-10-90								
				S.D. 51											
40	177-7	1190	8.2	156			0-0-30-70								
	179-2			263			0-0-20-80								
	1-2			135			0-0-50-50								
	1-7			13			0-0-70-30								
				Avg. 159			0-0-45-55								
				S.D. 97											
35	181-5	1040	7.2	375			0-0-40-60								
	176-7			531			0-0-30-70								
	2-3			109			0-0-70-30								
	2-2			159			0-0-40-60								
	2-5			672+	2970	20.5	0-0-40-60								
				Avg. > 369			0-0-45-55								
				S.D. 240											

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-7

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 9320 ADHESIVE AT 200°F (93°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
20	107-3	460	3.2	35			0-0-70-30	25	57-4	420	2.9	11			0-0-60-40
	108-3			8			0-0-80-20		63-1			2			0-0-60-40
	111-7			1			0-0-70-30		66-5			15			0-0-90-10
	112-7			1			0-0-70-30		58-3			2			0-0-80-20
	113-1			5			0-0-70-30		65-3			14			0-20-40-30
	108-1			56			0-0-30-70		62-2			2			0-0-40-60
	115-3			17			0-0-40-60								
				Avg. 18			0-0-60-40					Avg. 8			0-0-60-40
				S.D. 2								S.D. 6			
15	113-5	350	2.4	61			0-0-70-30	20	57-3	330	2.3	62			0-0-80-20
	114-7			58			0-0-70-30		58-6			17			0-0-70-30
	115-4			25			0-0-60-40		59-7			333			0-0-70-30
	107-5			45			0-0-90-10		60-5			113			0-0-80-20
	108-5			56			0-0-90-10		62-3			85			0-0-60-40
	112-4			41			0-0-80-20		66-2			69			0-0-80-20
	110-1			18			0-0-60-40		65-1			86			0-0-40-60
	111-3			56			0-0-50-50		61-1			36			0-0-80-20
	115-6			15			0-0-40-60		59-2			39			0-0-70-30
	116-4			58			0-0-50-50								
				Avg. 43			0-0-65-35					Avg. 93			0-0-70-30
				S.D. 18								S.D. 95			
10	116-5	230	1.6	672+	650	4.5	0-0-70-30	15	58-1	250	1.7	672+	1020	7.0	0-0-70-30
	167-2			672+	750	5.2	0-0-60-40		59-4			112			0-0-60-40
	110-7			672+	750	5.2	0-0-60-40		60-7			66			0-0-70-30
	111-4			672+	640	4.4	0-0-80-20		61-3			672+	740	5.1	0-0-80-20
	107-2			672+	630	4.3	0-0-70-30		64-3			457			0-0-60-40
	112-1			672+	800	5.5	0-0-70-30		57-7			672+	730	5.0	0-0-70-30
	113-2			672+	670	4.6	0-0-40-60		63-2			672+	950	6.6	0-0-60-40
	114-5			672+	880	6.1	0-0-60-40		60-6			672+	810	5.6	0-0-70-30
				Avg. >672	720	5.0	0-0-65-35					Avg. > 499	850	5.9	0-0-65-35
				S.D. 0	90	0.6						S.D. 264	129	0.9	

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-8

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 9324 ADHESIVE AT 200°F (93°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
30	125-3	670	4.6	3			0-0-0-100	30	70-7	770	5.3	1			0-0-20-80
	168-2			13			0-0-20-80		71-1			40			0-0-20-80
	117-2			79			0-0-10-90		68-5			60			0-0-20-80
	118-1			88			0-0-20-80		72-7			16			0-0-30-70
	119-1			66			0-0-30-70		73-3			2			0-0-10-90
	124-3			156			0-0-10-90		69-6			35			0-0-10-90
	120-2			69			0-0-10-90		74-3			321			0-0-20-80
	121-5			152			0-0-10-90		75-6			74			0-0-10-90
	123-3			86			0-0-10-90								
				Avg. 79			0-0-15-85					Avg. 69			0-0-20-80
				S.D. 52								S.D. 105			
								25	67-5	640	4.4	47			0-0-10-90
25	122-5	560	3.9	155			0-0-20-80		73-5			171			0-0-20-80
	123-5			107			0-0-10-90		158-3			181			0-0-20-80
	124-4			108			0-0-10-90								
	121-3			297			0-0-10-90					Avg. 133			0-0-20-80
	123-1			88			0-0-10-90					S.D. 77			
	117-3			325			0-0-10-90								
	118-5			256			0-0-0-80	20	67-7	510	3.5	240			0-0-20-80
	119-6			158			0-0-20-80		68-6			182			0-0-20-80
	12601			106			0-0-20-80		69-1			408			0-0-30-70
									72-4			323			0-0-40-60
				Avg. 178			0-0-15-85		70-3			381			0-0-30-70
				S.D. 91					71-3			517			0-0-30-70
									74-4			398			0-0-30-70
20	117-7	450	3.1	399			0-0-20-80								
	118-6			311			0-0-20-80					Avg. 349			0-0-30-70
	119-2			672+	1870	12.9	0-0-0-100					S.D. 112			
	120-5			404			0-0-60-40								
	121-7			672+	2190	15.1	0-0-0-100	15	69-7	380	2.6	280			0-0-50-50
	122-4			672+	2300	15.9	0-0-0-100		70-6			672+	2170	15.0	0-0-10-90
	124-2			561			0-0-20-80		71-4			672+	1750	12.1	0-0-10-90
	125-1			672+	1200	8.3	0-0-0-100		67-6			423			0-0-10-90
	126-2			418			0-0-20-80		68-4			672+	1700	11.7	0-0-0-100
				Avg. >531	1890	13.1	0-0-30-70					Avg. >544	1873	13.0	0-0-15-85
				S.D. 148	495	3.4						S.D. 183	258	1.8	

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-9

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 934 ADHESIVE AT 200°F (93°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
35	143-6	870	6.0	12			0-0-40-60	35	87-2	890		186			0-0-20-80
	144-3			3			0-0-10-90		88-6			207			0-0-20-80
	145-1			3			0-0-10-90		91-3			672+	1950	13.4	0-0-40-60
	138-7			64			0-0-20-80		93-1			108			10-0-20-70
	139-5			322			0-0-20-80		162-2			225			0-0-20-80
	140-7			353			0-0-20-80		95-5			672+	1810	12.5	10-0-30-60
	137-4			224			0-0-0-100		169-7			155			0-0-20-80
	141-4			242			0-0-10-90								
	142-5			315			0-0-30-70					Avg. > 318	1880	13.0	0-0-20-80
												S.D. 245			
				Avg. 173			0-0-15-85								
				S.D. 152				30	91-2	760	5.2	664			0-0-10-90
									161-4			1			0-0-10-90
30	142-4	740	5.1	405			0-0-40-60		89-1			672+	1830	12.6	0-0-40-60
	146-5			383			0-0-40-60		90-6			371			0-0-40-60
	137-7			672+	1410	9.7	0-0-10-90		91-1			672+	2410	16.6	0-0-40-60
	141-2			672+	2400	16.5	0-0-40-60					Avg. > 476	2120	14.6	0-0-25-75
	142-3			672+	2610	18.0	0-0-50-50					S.D. 295			
	139-6			492			0-0-10-90								
				Avg. > 549	2140	14.7	0-0-30-70	25	87-4	630	4.3	278			0-0-10-90
				S.D. 139	641	4.4			88-5			268			0-0-30-70
									161-5			241			0-0-40-60
25	141-1	620	4.3	672+	1710	11.8	0-0-40-60		93-4			594			50-0-20-30
	138-6			672+	1910	13.2	0-0-10-90		89-2			672+	1550	10.7	0-0-20-80
	144-2			672+	2250	15.5	0-0-30-70		90-7			672+	2210	15.2	0-0-20-80
				Avg. > 672	1960	13.5	0-0-25-75					Avg. > 454	1880	13.0	0-0-25-75
				S.D. 0	273	1.9						S.D. 212			
								20	87-5	510	3.5	672+	1890	13.0	0-0-20-80
									88-1			672+	1730	11.9	0-0-30-70
									89-5			672+	1550	10.7	0-0-40-60
									90-5			672+	2320	16.0	0-0-30-70
												Avg. > 672	1875	12.9	0-0-30-70
												S.D. 0	329	2.3	

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-10

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 3501 ADHESIVE AT 200°F (93°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
55	132-5	260	1.8	672+	580	4.0	0-0-10-90	35	79-2	200	1.4	672+	430	3.0	0-0-10-90
	170-1			336			0-0-30-70		84-4			672+	570	3.9	0-0-10-90
				Avg. >404			0-0-20-80		80-1			672+	570	3.9	0-0-20-80
									159-2			230			0-0-10-90
									85-7			58			0-0-60-40
50	133-6	240	1.7	22			0-0-20-80					Avg. >661	520	3.6	0-0-20-80
	135-4			672+	670		0-0-20-80					S.D. 276	84	0.5	
	127-5			672+	580	4.1	0-0-10-90								
	128-6			672+	590	4.1	0-0-10-90	30	81-7	170	1.2	672+	490	3.4	0-0-20-80
	134-5			610			0-0-20-80		77-4			672+	430	3.0	0-0-0-100
	131-3			74			0-0-60-60		159-1			672+	490	3.4	0-0-10-90
									85-1			8			0-0-30-70
				Avg. >453	620	4.1	0-0-25-75		159-3			672+	470	3.2	0-0-20-80
				S.D. 316	46				160-5			26			0-0-30-70
									77-3			672+	520	3.6	0-0-20-80
45	129-6	210	1.5	672+	570	3.9	0-0-10-90		81-2			672+	520	3.6	0-0-20-80
	170-2			672+	560	3.9	0-0-10-90		82-2			672+	510	3.5	0-0-10-90
	171-2			672+	560	3.9	0-0-10-90		85-7			93			0-0-60-40
									87-4			672+	620	4.3	0-0-20-80
				Avg. >672	570	3.9	0-0-10-90					Avg. >694	510	3.5	0-0-25-75
				S.D. 0	0	0						S.D. 297	55	0.4	
								20	77-7	120	0.8	672+	530	3.7	0-0-10-90
									160-7			672+	460	3.2	0-0-10-90
									80-7			672+	630	4.3	0-0-10-90
												Avg. >672	540	3.7	0-0-10-90
												S.D 0	85	0.6	

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 3.

TABLE G-11

INDIVIDUAL STRESS-DURABILITY DATA WITH EPIBOND 1524 ADHESIVE AT 200°F (93°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
30	151-4	940	6.5	223			0-0-40-80	40	163-6	1260	8.7	2			0-0-10-90
	156-4			181			0-0-80-20		164-7			2			0-0-40-60
	147-2			193			0-0-40-60					Avg. 2			0-0-25-75
	149-1			261			0-0-70-30								
	155-1			333			0-0-60-40								
				Avg. 238			0-0-60-40	30	104-7	950	6.5	1			0-0-60-40
				S.D. 61					106-4			286			0-0-60-40
									101-1	228		226			0-0-50-50
25	149-2	780	5.4	375			0-0-40-60		103-5			18			0-20-70-10
	150-1			313			0-10-40-50		106-7			2			0-20-70-10
	155-4			350			0-0-70-30		166-7			178			0-0-60-40
	148-1			518			0-10-30-60		105-7			306			0-0-50-50
	151-7			203			0-0-90-10		100-6			230			0-0-40-60
	156-2			348			0-0-80-20		98-6			517			0-0-40-60
	153-3			41			0-0-60-40					Avg. 196			0-0-55-45
				Avg. 335			0-0-60-40					S.D. 171			
				S.D. 176											
								25	96-7	790	5.4	231			0-0-40-60
20	147-4	630	4.3	412			0-0-20-70		100-1			520			10-0-30-60
	149-7			364			0-0-60-40		102-2			321			0-0-60-40
	154-4			344			0-0-70-30		104-2			313			0-10-60-30
	172-3			382			0-0-60-40		99-2			672+	1390	44	0-0-30-70
	172-4			513			0-0-40-60		165-4			392			0-0-40-60
	154-2			499			0-10-30-60		163-3			188			90-0-0-10
				Avg. 419			0-0-50-50		102-3			399			0-0-50-50
				S.D. 71					101-7			255			0-10-70-20
												Avg.>366			10-0-45-45
15	151-2	470	3.2	672+	1850		0-0-40-60					S.D. 153			
	147-6			672+	2310		0-0-30-70								
				Avg.>672	2080		0-0-35-65	20	98-5	630	4.3	401			0-0-40-60
									99-4			388			0-0-50-50
									100-7			450			0-0-60-40
									101-4			425			0-0-70-30
									165-1			573			0-0-30-50
									164-3			414			0-0-40-60
												Avg. 442			0-0-50-50
												S.D. 68			

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

TABLE G-12

INDIVIDUAL STRESS-DURABILITY DATA WITH EA 934 NA ADHESIVE AT 200°F (93°C), 95-100% R.H.

6061 T6 Aluminum Adherend								5052-H34 Aluminum Adherend							
Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]	Nominal Stress Level(%)[1]	Spec. No.	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Stress (psi)	Residual Stress (MPa)	Failure Mode[2]
40	178-4	680	4.7	18			0-0-30-70								
	1-5			13			0-0-30-70								
	1-6			13			0-0-40-60								
	2-6			1			0-0-40-60								
	2-7			3			0-0-40-60								
	3-6			376			0-0-40-60								
				Avg. 71			0-0-40-60								
				S.D. 150											
35	179-3	590	4.1	672+	1475	10.2	0-0-30-70								
	174-6			131			0-0-20-80								
	2-4			672+	1750	12.1	0-0-30-70								
	3-1			672+	1320	9.1	0-0-30-70								
	3-3			672+	1160	8.0	0-0-30-70								
	3-4			672+	1280	8.8	0-0-30-70								
	3-5			672+	1350	9.3	0-0-40-60								
				Avg.>595	1390	9.6	0-0-30-70								
				S.D. 205	204	1.4									
45	182A-1	760	5.3	4			0-0-30-70								
	3-7			4			0-0-40-60								
				Avg. 4			0-0-35-65								
				S.D. 0											

[1] The nominal stress level represents the percent of the unaged, as-fabricated static strength of this adhesive/adherend combination at the exposure temperature.

[2] See Figure 2.

APPENDIX H
TEST DATA FOR EC2216 AND EC2054

TABLE H-1

INDIVIDUAL LAP SHEAR TEST RESULTS FOR EC2216
ON 6061-T6 ADHERENDS

Test Temperature (°F)	(°C)	Aging Condition	Strength (psi)	(MPa)	Failure Mode[1]
-65	-54	None	2480	17.09	0-0-100-0
			2210	15.23	0-0-100-0
			2280	15.71	0-0-100-0
			2570	17.71	0-0-90-10
			2350	16.19	0-0-100-0
Avg.			2380	16.40	0-0-100-0
Std.Dev.			140	0.96	
72	22	None	2350	16.19	0-0-20-80
			2800	19.29	0-0-10-90
			3210	22.12	0-0-30-70
			2870	19.77	0-0-70-30
			3190	21.98	0-0-10-90
Avg.			2880	19.84	0-0-30-70
Std.Dev.			350	2.41	
140	60	None	1050	7.23	0-0-30-70
			1280	8.82	0-0-10-90
			1200	8.27	0-0-20-80
			1530	10.54	0-10-10-80
			1510	10.40	0-10-30-60
Avg.			1310	9.03	0-5-20-75
Std.Dev.			210	1.45	
200	93	None	700	4.82	0-0-20-80
			510	3.51	0-0-60-40
			930	6.41	0-0-0-100
			350	2.41	0-0-70-30
			460	3.17	0-0-60-40
Avg.			590	4.07	0-0-40-60
Std.Dev.			230	1.58	
140	60	14 days @ 140°F (60°C) and 95-100% R.H.	660	4.55	0-0-0-100
			760	5.24	0-0-10-90
			880	6.06	0-0-30-70
			590	4.07	0-0-30-70
			640	4.41	0-0-30-70
Avg.			710	4.89	0-0-20-80
Std.Dev.			120	0.83	
200	93	14 days @ 200°F (93°C) and 95-100% R.H.	490	3.38	5-0-60-35
			540	3.72	0-0-0-100
			510	3.51	0-0-60-40
			440	3.03	0-0-30-70
			500	3.45	0-0-10-90
Avg.			500	3.45	0-0-30-70
Std.Dev.			40	0.28	

[1]See Figure 2.

TABLE H-2

INDIVIDUAL LAP SHEAR TEST RESULTS FOR EC2054 ON 6061-T6 ADHERENDS

Test Temperature (°F)	(°C)	Aging Condition	Strength (psi)	(MPa)	Failure Mode[1]
-65	-54	None	2130	14.68	0-0-100-0
			2030	13.99	0-25-75-0
			2050	14.12	0-0-100-0
			2120	14.61	0-0-100-0
			1890	13.02	25-0-75-0
Avg.			2040	14.06	5-5-90-0
Std.Dev.			100	0.69	
72	22	None	2990	20.60	0-0-100-0
			3280	22.60	0-0-100-0
			3200	22.05	0-0-100-0
			2970	20.46	0-0-100-0
			3320	22.87	0-0-100-0
Avg.			3150	21.70	0-0-100-0
Std.Dev.			160	1.10	
140	60	None	2350	16.19	0-0-0-100
			2080	14.33	0-0-10-90
			1740	11.99	0-0-10-90
			1690	11.64	0-0-0-100
			1680	11.58	0-0-0-100
Avg.			1910	13.16	0-0-5-95
Std.Dev.			300	2.07	
200	93	None	570	3.93	0-0-0-100
			580	4.00	0-0-0-100
			580	4.00	0-0-0-100
			570	3.93	0-0-0-100
			610	4.20	0-0-0-100
Avg.			580	4.00	0-0-0-100
Std.Dev.			20	0.14	
140	60	14 days @ 140°F (60°C) and 95-100% R.H.	1040	7.17	0-0-0-100
			860	5.93	0-0-0-100
			830	5.72	0-0-0-100
			800	5.51	0-0-0-100
			940	6.48	0-0-0-100
Avg.			890	6.13	0-0-0-100
Std.Dev.			100	0.69	
200	93	14 days @ 200°F (93°C) and 95-100% R.H.	460	3.17	0-0-0-100
			500	3.45	0-0-0-100
			520	3.58	0-0-0-100
			480	3.31	0-0-0-100
			490	3.38	0-0-0-100
Avg.			490	3.38	0-0-0-100
Std.Dev.			30	0.21	

[1]See Figure 2.

TABLE H-3

INDIVIDUAL STRESS-DURABILITY DATA FOR EC2216 ADHESIVE ON 6061-T6 ADHERENDS AT 140°F (60°C) AND 95-100% R.H.

Nominal Stress Level (%)[1]	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Strength (psi)	Residual Strength (MPa)	Failure Mode[3]
25	329	2.27	2.6	---	---	0-0-90-10
			24	---	---	0-0-80-20
			362	---	---	0-0-90-10
			14	---	---	10-10-0-80
			23	---	---	0-0-40-60
			327	---	---	0-0-10-90
Avg.			125	---	---	2-2-50-55
Std.Dev.			170	---	---	
20	263	1.81	232	---	---	0-0-70-30
			144	---	---	0-0-30-70
			672+[2]	1020	7.03	0-0-0-100
			672+[2]	680	4.68	0-0-60-40
			672+[2]	620	4.27	0-0-70-30
			672+[2]	920	6.34	0-0-70-30
Avg.			>511	810	5.58	0-0-50-50
			251	190	1.32	
15	197	1.36	672+[2]	750	5.17	0-0-30-70
			672+[2]	570	3.93	0-0-10-90
Avg.			672+	660	4.55	0-0-20-80

[1] % of 140°F (60°C) dry ultimate lap shear strength.

[2] Specimens survived for 28 days without failure and were removed for residual strength testing at the same temperature as they saw during exposure.

[3] See Figure 2.

TABLE H-4

INDIVIDUAL STRESS-DURABILITY DATA FOR EC2216 ADHESIVE ON 6061-T6 ADHERENDS AT 200°F (93°C) AND 95-100% R.H.

Nominal Stress Level (%)[1]	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Strength (psi)	Residual Strength (MPa)	Failure Mode[3]
70	399	2.75	2	---	---	0-0-60-40
			18	---	---	0-0-10-90
Avg.			10	---	---	0-0-35-65
65	371	2.55	2	---	---	0-0-60-40
			18	---	---	0-0-10-90
			16	---	---	0-0-50-50
			16	---	---	0-0-40-60
			3.5	---	---	0-0-10-90
			672+[2]	710	4.89	0-0-0-100
Avg.			>121	---	---	0-0-30-70
Std.Dev.			270	---	---	
60	342	2.36	17	---	---	0-0-60-40
			110	---	---	0-0-20-80
			148	---	---	0-0-30-70
			672+[2]	580	4.00	0-0-10-90
			17	---	---	0-0-40-60
			17	---	---	0-0-50-50
Avg.			>164	---	---	0-0-35-65
Std.Dev.			255	---	---	
55	314	2.16	3	---	---	0-0-40-60
			85	---	---	0-0-20-80
			38	---	---	0-0-30-70
			85	---	---	0-0-40-60
			672+[2]	690	4.75	0-0-0-100
Avg.			>177	---	---	0-0-25-75
Std.Dev.			279	---	---	
50	295	2.03	672+[2]	300	2.07	0-0-0-100
40	236	1.62	672+[2]	520	3.58	0-0-20-80
35	206	1.42	40	---	---	0-0-90-10
			672+[2]	450	3.10	0-0-10-90
			672+[2]	470	3.24	0-0-20-80
Avg.			>461	460	3.17	0-0-40-60
Std.Dev.			365	---	---	
25	147	1.01	672+[2]	570	3.92	0-0-10-90

[1] % of 200°F (93°C) dry ultimate lap shear strength.

[2] Specimens survived for 28 days without failure and were removed for residual strength testing at the same temperature as they saw during exposure.

[3] See Figure 2.

TABLE H-5

INDIVIDUAL STRESS-DURABILITY DATA FOR EC2054
ADHESIVE ON 6061-T6 ADHERENDS AT
140°F (60°C) AND 95-100% R.H.

Nominal Stress Level(%)[1]	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Strength (psi)	Residual Strength (MPa)	Failure Mode[3]
25	476	3.28	26	---	---	0-0-0-100
			24	---	---	0-0-10-90
			17	---	---	0-0-20-80
			14	---	---	0-0-20-80
			135	---	---	0-0-30-70
			66	---	---	0-0-20-80
Avg.			47	---	---	0-0-15-85
Std.Dev.			47	---	---	
20	381	2.63	313	---	---	0-0-10-90
			456	---	---	0-0-10-90
			350	---	---	0-0-20-80
			207	---	---	0-0-20-80
			672+[2]	1210	8.34	0-0-10-90
			300	---	---	0-0-10-90
Avg.			383	---	---	0-0-15-85
Std.Dev.			163	---	---	
15	286	1.97	68	---	---	0-0-10-90
			123	---	---	0-0-10-90
			672+[2]	1010	6.96	0-0-10-90
			672+[2]	1095	7.54	0-0-0-100
			672+[2]	1070	7.37	0-0-0-100
			672+[2]	1300	8.96	0-0-0-100
Avg.			>480	1120	7.71	0-0-5-95
Std.Dev.			298	130	0.87	

[1]% of 140°F (60°C) dry ultimate lap shear strength.

[2]Specimens survived for 28 days without failure and were removed for residual strength testing at the same temperature as they saw during exposure.

[3]See Figure 2.

TABLE H-4

INDIVIDUAL STRESS-DURABILITY DATA FOR EC2216
ADHESIVE ON 6061-T6 ADHERENDS AT
200°F (93°C) AND 95-100% R.H.

Nominal Stress Level (%)[1]	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hr)	Residual Strength (psi)	Residual Strength (MPa)	Failure Mode[3]
70	399	2.75	2	---	---	0-0-60-40
			18	---	---	0-0-10-90
Avg.			10	---	---	0-0-35-65
65	371	2.55	2	---	---	0-0-60-40
			18	---	---	0-0-10-90
			16	---	---	0-0-50-50
			16	---	---	0-0-40-60
			3.5	---	---	0-0-10-90
			672+[2]	710	4.89	0-0-0-100
Avg.			>121	---	---	0-0-30-70
Std.Dev.			270	---	---	
60	342	2.36	17	---	---	0-0-60-40
			110	---	---	0-0-20-80
			148	---	---	0-0-30-70
			672+[2]	580	4.00	0-0-10-90
			17	---	---	0-0-40-60
			17	---	---	0-0-50-50
Avg.			>164	---	---	0-0-35-65
Std.Dev.			255	---	---	
55	314	2.16	3	---	---	0-0-40-60
			85	---	---	0-0-20-80
			38	---	---	0-0-30-70
			85	---	---	0-0-40-60
			672+[2]	690	4.75	0-0-0-100
Avg.			>177	---	---	0-0-25-75
Std.Dev.			279	---	---	
50	295	2.03	672+[2]	300	2.07	0-0-0-100
40	236	1.62	672+[2]	520	3.58	0-0-20-80
35	206	1.42	40	---	---	0-0-90-10
			672+[2]	450	3.10	0-0-10-90
			672+[2]	470	3.24	0-0-20-80
Avg.			>461	460	3.17	0-0-40-60
Std.Dev.			365	---	---	
25	147	1.01	672+[2]	570	3.92	0-0-10-90

[1] % of 200°F (93°C) dry ultimate lap shear strength.

[2] Specimens survived for 28 days without failure and were removed for residual strength testing at the same temperature as they saw during exposure.

[3] See Figure 2.

TABLE H-6

INDIVIDUAL STRESS-DURABILITY DATA FOR EC2054 ADHESIVE ON 6061-T6 ADHERENDS AT 200°F (93°C) AND 95-100% R.H.

Nominal Stress Level(%)[1]	Exposure Stress (psi)	Exposure Stress (MPa)	Time to Failure (hrs)	Residual Strength (psi)	Residual Strength (MPa)	Failure Mode[3]
50	290	2.00	44	---	---	0-0-50-50
			37	---	---	0-0-40-60
			124	---	---	0-0-40-60
			105	---	---	0-0-30-70
			66	---	---	0-0-30-70
			672+[2]	540	3.72	0-0-10-90
Avg.			>175	---	---	0-0-35-65
Std.Dev.			246	---	---	
45	261	1.80	203	---	---	0-0-20-80
			189	---	---	0-0-30-70
			164	---	---	0-0-40-60
			123	---	---	0-0-20-80
			672+[2]	450	3.10	0-0-10-90
			672+[2]	580	4.00	0-0-10-90
Avg.			>337	520	3.58	0-0-20-80
Std.Dev.			260	---	---	
40	232	1.60	672+[2]	510	3.51	0-0-20-80
			672+[2]	440	3.03	0-0-30-70
			672+[2]	390	2.69	10-0-0-90
			672+[2]	355	2.45	0-0-0-100
			672+[2]	530	3.65	0-0-10-90
			672+[2]	640	4.41	0-0-10-90
Avg.			672+[2]	480	3.29	0-0-15-85
Std.Dev.			0	104	0.72	
35	203	1.40	253	---	---	0-0-10-90
			672+[2]	475	3.27	0-0-0-100
			>463	---	---	0-0-5-95
25	145	1.00	672+[2]	530	3.65	0-0-0-100

[1] % of 200°F (93°C) dry ultimate lap shear strength.

[2] Specimens survived for 28 days without failure and were removed for residual strength testing at the same temperature as they saw during exposure.

[3] See Figure 2.